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Social-Ecological Factors Affecting Patient Shield Use Among Radiologic and Computed Tomography Technologists

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Social-Ecological Factors Affecting Patient Shield Use Among Radiologic and Computed Tomography Technologists

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by

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ABSTRACT

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Medical radiation is estimated to contribute to over 200,000 deaths annually. Recent increases in the use of radiation-producing medical imaging examinations have led to increasing cumulative radiation dose to the general public. Multiple measures have been taken to address this alarming trend, including physician education, technologist education on dose reduction, and equipment-facilitated dose reduction techniques. Shield use can reduce the primary beam by up to 95%. Medical imaging technologists are the primary individuals responsible for applying shielding during an examination. Currently, literature shows that technologists are not shielding individuals as often as they should.

After pilot testing, medical imaging technologists were recruited via email to participate in a national cross-sectional survey in September 2017. The survey contained items related to technologists' demographics, shielding behaviors, and attitudes and beliefs measured at four Social-Ecological levels – intrapersonal, interpersonal, organizational, and community.

The American Registry of Radiologic Technologists (ARRT) provided a list of technologists' email addresses from their directory. One thousand six-hundred and sixty-one email notifications were sent out in the summer of 2017. Of those, 218 technologists (13%) completed the survey.

Among technologists who considered their primary modality to be computed tomography (CT), organizational level factors were a positive significant predictor of shielding behavior. None of the four levels were significant in predicting shielding behavior among diagnostic radiological technologists (x-ray). Individual factors were significantly correlated to shielding behavior among radiologic technologists in the intrapersonal, organizational, and community levels. Study results indicated that interventions implemented at the organizational level may be most effective in increasing shield use among CT technologists. Additional research is needed to better understand factors affecting shield use among medical imaging technologists.

DEDICATION

To my loving husband, Adam, thank you for voyaging though life with me. I did not do this dissertation alone, we did this together, every step of the way it has been you and me.

To my children, Eloise and Ira, for providing me with days full of laughter and love. You are each worth more than a million degrees. I love you both more than you will ever realize.

To my dad, Dr. Mitchell Housenick, my hero and the greatest x-ray tech I have ever known.

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Lastly, I would like to remember Wilhelm Conrad Roentgen for discovering x-rays over 100 years ago, giving the medical community such a valuable tool, and a career in which I adore.

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ACRONYMS AND ABBREVIATIONS

AAPM	American Associations of Physicists in Medicine
ACS	American Cancer Society
ACR	American College of Radiography
AEC	Automatic Exposure Control
ALARA	As Low As Reasonably Achievable
ASRT	American Society of Radiologic Technologists
ARRT	American Registry of Radiologic Technologists
CT	Computed Tomography
FDA	Food and Drug Administration
Gy	Gray
ICRP	International Commission on Radiation Protection
IR	Image receptor
kVp	Kilovoltage peak
LNT	Linear Non-Threshold
mAs	Milliamperage Seconds
MRI	Magnetic Resonance Imaging
mSv	Millisievert
NCRP	National Council on Radiation Protection and Measurements
RSNA	Radiological Society of North America
SPR	Society for Pediatric Radiology
SI	International System of Measurements
Sv	Sievert

CHAPTER 1

INTRODUCTION

Background of the Study

Since the 1980s, total exposure to ionizing radiation from medical procedures among the general public has tripled (National Council on Radiation Protection and Measurements [NCRP], 2009). This increase in total exposure has been attributed to increased use of radiologic medical procedures such as computed tomography (CT). Over 3.6 billion radiologic procedures were performed between 2000 and 2007, of which 3.1 billion were diagnostic radiologic procedures (e.g., general radiography and CT) (Mettler et al., 2009). Increased cumulative radiation dose to radiosensitive organs over time has the possibility to increase an individual's risk for cancer later in life (National Academy of Science, 2006). Shielding patients with lead-equivalent barriers during general radiologic examinations or with bismuth for CT procedures can reduce radiation dose to radiosensitive organs, including reproductive organs, breast tissue, thyroid, and eyes, and shielding can lower individual risk of radiation-induced cancers (Bushong, 2017).

Previously, the largest contributor to the general population's ionizing radiation dose was from background sources, including cosmic, terrestrial, and internal radiation sources. These background sources account for an average 3 millisievert (mSv) (1000 mSv = 1 Sievert) of radiation per individual annually. Radiation is commonly measured in Sieverts (Sv) which is an International System of Units (SI) "of equivalent dose, effective dose, and operational dose quantities" and represents the biological effect on the human body (International Commission on Radiological Protection [IRCP], 2007). Recently, medical radiation dose has increased drastically and now contributes more to annual radiation dose than background sources, with 48% of the annual dose now coming from medical examinations. Figure 1 shows that of this

48% from medical procedures, CT comprises 24%; nuclear medicine, 12%; interventional, 7%; and conventional/general radiography and fluoroscopy, 5% (NCRP, 2009). While much of this dose is attributed to more frequent use of CT, general radiographic examinations still comprise the largest number of medical imaging examinations performed, contributing to increased cumulative dose.

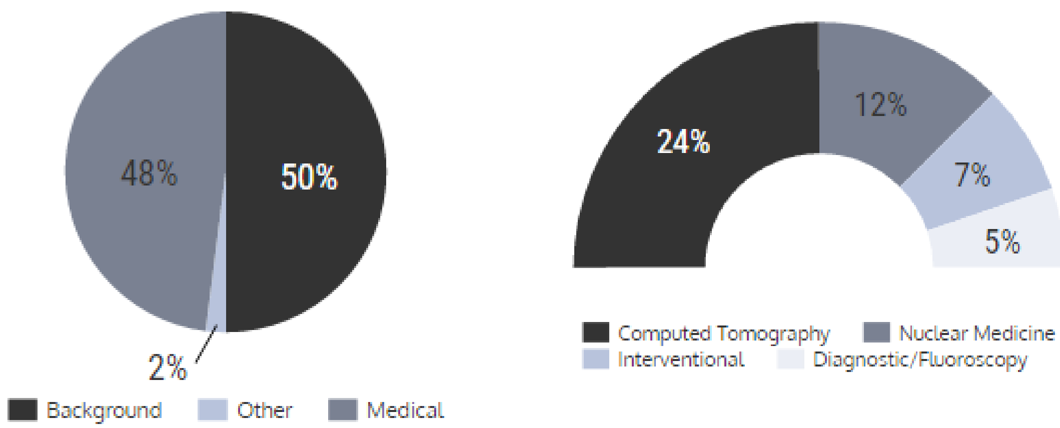


Figure 1. Sources of radiation exposure (adapted from NCRP, 2009)

Radiation-induced cancer has been studied in multiple groups including radioactive bomb survivors, medically exposed groups, environmentally exposed communities, and occupationally exposed populations. These studies found radiation exposure to be associated with leukemia, breast, bladder, colon, lung, and thyroid cancers. Previous research on these populations has determined that doses of 100 mSv or more within a 5-year period significantly increased cancer risk in exposed populations (Nuclear Radiation Agency, 1996; Preston et al., 2007). There is debate about the causal link between exposure and cancer incidence at doses less than 100 mSv; however, some studies have shown that radiation exposures above 10 mSv – the dose of certain

CT examinations – may also increase cancer risk to 1 in 1,000 individuals (Hendee & O'Connor, 2012; Hricak et al., 2011).

The NCRP and International Commission on Radiological Protection (ICRP) have the recommended standard of 1 mSv of continuous exposure and 5 mSv of infrequent exposure for the maximum permissible radiation dose annually for the general public (NCRP, 1993). These standard exposure doses are based in literature surrounding health effects of radiation while also maintaining lowest exposure rates to be cautious of unknown effects. While most general radiographic examinations do not exceed these standard dose recommendations, dose for CT studies can be as high as 25 mSv per examination (Einstein, 2012). Additionally, repetitive medical radiation examinations can increase an individual's cumulative dose over a short period of time, allowing for general radiographic examinations to exceed the recommended 1 mSv dose and CT examinations to meet or exceed the 100 mSv dose significant for cancer risk (Nuclear Radiation Agency, 1996; Preston et al., 2007).

Radiation exposure follows a linear non-threshold trajectory in the theory that as the dose of radiation increases, the risk for cancer increases proportionately. Therefore, those receiving higher doses of radiation are suspected to be at a higher risk of cancer. Due to the nature of radiation-induced cancers, most do not appear until one to two decades post-exposure. Recent literature has estimated that nearly 29,000 future cancers will be attributable to CT studies done in 2007 alone (Berrington de Gonzalez et al., 2009).

Methods to decrease a patient's medical radiation dose include reducing exposure time, increasing distance from the primary beam, and applying lead-equivalent shielding. These are the primary principles of radiation protection and assist in keeping patient dose as low as reasonably achievable, a phrase often abbreviated as ALARA.

Radiologic and CT technologists are trained medical professionals who apply radiation for medical imaging procedures and have control over the dose that an individual receives during a radiographic examination. Since the effects of low dose radiation on the body are not fully known, radiation protection standards suggest that lead-equivalent shielding barriers be applied to all individuals whenever they do not interfere with the anatomy of interest, regardless of age or gender.

Investigator's Personal Experience with the Topic

The investigator of this dissertation research has been a registered technologist for over 10 years. During her time in radiology and CT, she saw that the majority of patients were not being shielded during routine examinations. This included individuals of child-bearing age for examinations where shielding would not compromise the image, such as chest radiographs. For CT examinations, a bismuth breast shield was available but rarely used within the facility in which she worked. Much of the investigator's radiography education was based on patient radiation safety and protection and shield use was emphasized during positioning didactic courses. Additionally, approximately 25% of the test questions on the American Registry of Radiologic Technologists (ARRT) certification examination are allocated to radiation safety (ARRT, 2017). These factors led her to wonder why shielding was not being applied during clinical practice.

Purpose of the Study

The purpose of this study is to explore behaviors, beliefs, and attitudes about shielding patients for general radiography and CT medical examinations among a national sample of registered technologists[1]. The investigator analyzed these data to examine perceived barriers to shielding patients during routine diagnostic radiographic and CT examinations and to determine

[1]For the purpose of this study, registered technologist is defined as any individual who has met the requirements for and passed the examinations set forth by the American Registry of Radiologic Technologists (ARRT).

at which level (intrapersonal, interpersonal, or organizational) an intervention could most effectively improve the likelihood of technologists implementing proper shielding methods. Medical imaging facilities and health services managers could use this survey tool in the future to assess perceived barriers within their departments and intervene to reduce patient exposure with the ultimate goal of decreasing radiation induced cancers and saving lives. This national study therefore addresses the implications of the public's cumulative radiation dose to radiosensitive organs and increased risk of radiation-induced cancers resulting from lack of shielding during medical imaging studies.

Conceptual Model Guiding the Study

The Bronfenbrenner original ecological model contains five social levels: individual (intrapersonal), microsystem (interpersonal), mesosystem (community), exosystem (organizational), and macrosystem (public policy). This model is often used to explain how social and physical environments affect human growth and how these levels interact to impact an individual's overall development (Bronfenbrenner, 1994). Since the development of this model, its use has expanded from physiological human development into public health and health behavior.

The conceptual model for this study is a modified ecological model (Figure 2) consisting of three levels: intrapersonal, interpersonal, and organizational. The ecological model is often used to show relationships between multiple levels of an individual's environment and how those levels affect health behavior. This conceptual health model is beneficial in determining areas of intervention on a behavior while taking into consideration how each level can shape an individual's behavior (National Cancer Institute, 2005).

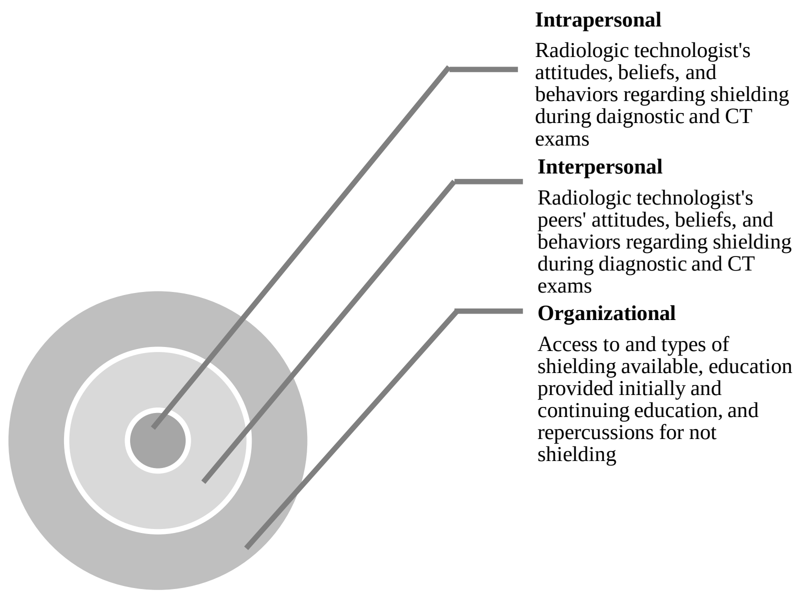


Figure 2. Theoretical framework – modified ecological model (adapted from Bronfenbrenner, 1979).

The intrapersonal level of this modified ecological model includes those factors that are specific to the individual technologist. These include the technologist's attitudes, beliefs, and behaviors about using lead or bismuth shielding during general radiographic and CT examinations. The technologist's intentions and willingness to apply shielding, perceived behavioral control, perceived severity of not shielding, and knowledge of proper shielding and radiation exposure risks are also included in the intrapersonal level.

The second level, interpersonal or social norms, consists of peer attitudes, beliefs, and behaviors regarding shielding patients for examinations. This level focuses on other technologists within the work environment and how their behaviors and beliefs affect the shielding behaviors of their fellow technologists.

Lastly, the organizational level involves factors related to the organization or department in which the technologist works. This includes, but is not limited to, access to and types of shields available, primary shielding education and continuing education, repercussions for not shielding, and reward systems in place for shielding.

The community and public policy levels were not included in this study. While interventions at these levels are possible, they are beyond the scope of the study as the target audience is radiologic and CT technologists. Interventions in the community and public policy would need to be handled delicately to prevent public fear of radiation and technologist fear of repercussions from governing boards such as the American Registry of Radiologic Technologists (ARRT). Due to the lack of public knowledge surrounding radiation terminology, dose, and safety, an intervention at the community level could cause panic in the population over the radiation levels of medical imaging procedures (Hudzietzova & Jozef, 2014). If risk communication is not handled correctly, it could lead to negative health outcomes to members of the public. Due to fears of radiation effects, some individuals may refuse examinations that are necessary for diagnosis and management of health conditions leading to increased morbidity and mortality. Additionally, interventions at the public policy level may be difficult due to lack of current ability to properly track overall shielding and enforce consequences on technologists who do not shield patients. This would also present an issue with technologists at smaller facilities who may not have access to newer technologies such as bismuth shields for CT imaging, leading to repercussions for factors they do not have control over.

Significance and Innovation

The study is significant because radiation from medical examinations has increased from 15% to 48% of the population's overall cumulative radiation dose in the previous 20-30 years

(NCRP, 2009). Much of the previous research in dose reduction has focused on decreasing the number of exams ordered by physicians. Little research has focused on radiologic technologists' role in dose reduction. Radiologic technologists play a large role in reducing an individual's dose during the majority of general radiography and CT medical examinations through application of the radiation protection principles of decreasing time of exposure, increasing patient distance from the primary beam, and implementing shielding methods. Data gathered from this study point to "target areas" at different levels of the ecological model in which an intervention to increase technologists' use of shielding would prove most effective.

Research Aims

The aims of this research are:

Research Aim 1

To assess perceived barriers to shielding patients during medical imaging examinations among radiologic and computed tomography technologists.

Research Aim 2

To determine at which level of the ecological model an intervention to improve technologists' use of shielding would be most effective.

CHAPTER 2

LITERATURE REVIEW

Introduction

On November 8, 1895, Wilhelm Conrad Roentgen observed the ability of invisible rays to penetrate a number of materials including bodily soft tissues. He named these rays “x-rays” to differentiate them from other electromagnetic rays. Soon after their discovery, scientists began to experiment with x-rays to determine possible applications. It was quickly realized that the x-ray had dangerous properties after many of these researchers began to experience side effects from prolonged exposure, including burns, skin erythema, and decreased vision.

While the likelihood of such high doses during a one-time exposure leading to skin burns or radiation sickness is unlikely in radiography and CT, other serious latent issues from exposure can be detrimental to the public’s health and wellbeing. These include genetic mutations in future generations and radiation-induced cancers. Radiation-induced cancers are unable to be differentiated from cancers caused by other factors. These radiation-induced cancers contribute to the public’s already large burden of cancer – an estimated 1,685,210 new cases and 595,690 deaths in the United States for 2016 (American Cancer Society [ACS], 2016). Genetic mutations are also concerning as the effects will not be seen until future offspring, and it is unknown how these conditions will affect healthcare and the general public.

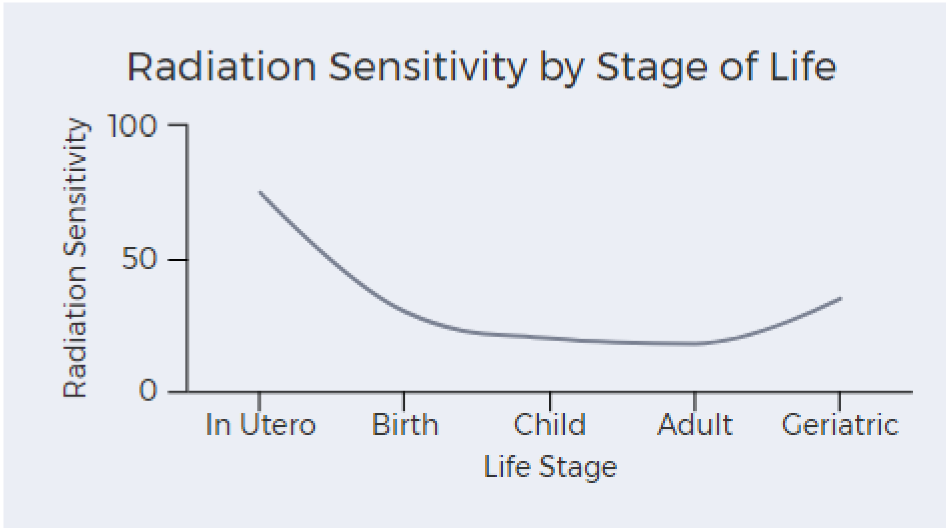
Licensed healthcare professionals including physicians, radiologists, and radiologic technologists all play a role in reducing patient radiation dose to avoid adverse effects. Physicians are responsible for justifying the need for the procedure that delivers radiation (x-ray, CT) as opposed to non-radiation procedures such as ultrasound and magnetic resonance imaging (MRI). The American College of Radiology (ACR) provides healthcare practitioners access to the ACR Appropriateness Criteria rating tables that assist in justification of medical imaging procedures (American College of Radiology, 2017). Radiologists assist in reducing dose through creating and implementing low-dose protocols within their healthcare facility and guiding ordering physicians in selecting proper examinations when needed. Radiologic technologists can play a crucial role in reducing patient radiation dose, as they are responsible for administering 80% of medical radiation to patients (World Health Organization, 2008).

Health Effects of Radiation Exposure

Radiation Sensitivity

Multiple biological factors determine an individual's radio-sensitivity and the radio-sensitivity of different organs in the body. These include age of the individual, gender, age of the cell, cell metabolic rate, tissue type, and oxygen enhancement (Bushong, 2017).

Figure 3 indicates the relationship between age and radio-sensitivity. The fetus in the first trimester of pregnancy is the most sensitive to the effects of radiation exposure. Exposure during this period can have adverse effects on the unborn child such as deformities, increased risk of cancer, or spontaneous abortion/death. This radiation sensitivity is high in utero, decreases over an individual's lifetime, and starts increasing again much later in life. During the fetal stage, cells are rapidly undergoing mitosis which makes them more sensitive to radiation exposure. During the later stages of life, these cells deteriorate and function less precisely, making it difficult for the cells to repair after being exposed to radiation. Females have also been found to be more radiosensitive than males (Bushong, 2017).



*Numbers on y-axis are not a direct representation of sensitivity level

Figure 3. Radiation sensitivity by stage of life (adapted from Bushong, 2017).

Additionally, different types of cells or tissues within the human body are more sensitive to radiation exposure than others. Breast, bone marrow, colon, lung, ovaries, stomach and testes are the most radiosensitive. The bladder, liver, esophagus, and thyroid have a moderate level of radio-sensitivity. The least sensitive tissues are bone, brain, heart, kidneys, pancreas, prostate, salivary glands, skin, and uterus (Picano et al., 2014). Much of what determines this radio-sensitivity is how quickly the cell proliferates; those with faster proliferation are more radiosensitive than those cells that proliferate more slowly.

Radiation Dose Response to the Human Body

There are 2 types of dose exposure: early nonstochastic (deterministic) somatic effects and late stochastic (probabilistic) somatic effects. Early nonstochastic effects involve full-body exposure to high doses of radiation over a short (acute) period of time. This type of somatic effect has been identified in individuals exposed to nuclear radiation explosions at Hiroshima, Nagasaki, and Chernobyl (Sherer, Visconti, & Riternour, 2006). Late stochastic effects involve lower doses of radiation exposure over a longer (chronic) period of time. This may include natural exposure to natural background radiation such as radon, cosmic, terrestrial, and internal as well as manmade (artificial) radiation such as medical radiation over time.

Deterministic effects are those that have a direct relationship with the amount of radiation exposure and have a threshold below which a response will not occur (Bushong, 2017). This type of effect is known as following a curvilinear threshold model (Figure 4). The latency period for deterministic effects is days or weeks. Common biological responses include hair loss, skin erythema, cataracts, and acute radiation syndrome (ARS). The radiation threshold level varies for the different types of responses. For example, skin erythema can occur between 3-10 Gy (Gray) and temporary male sterility has a threshold as low as 0.3 Gy. The Gy is an International System (SI) unit for radiation absorbed energy per unit mass of tissue (IRCP, 2007).

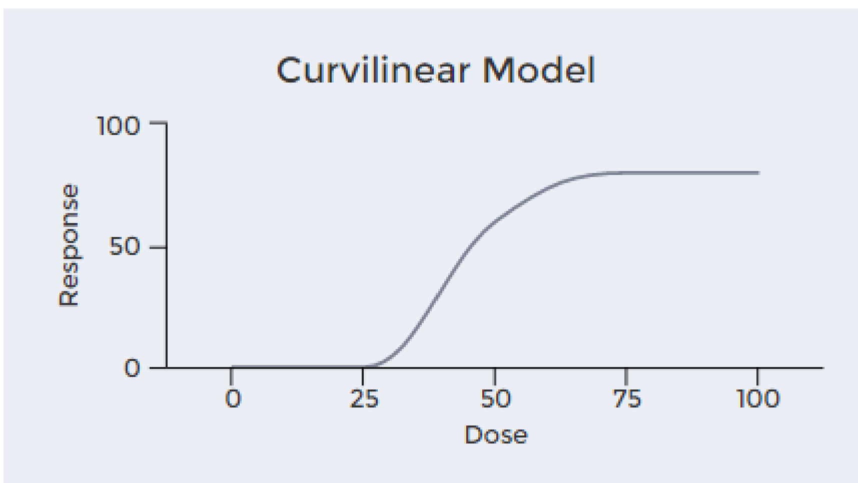


Figure 4. Curvilinear threshold model (adapted from Bushong, 2017).

Probabilistic effects happen by chance and may take many years to occur. It is most commonly believed that probabilistic effects follow a linear non-threshold (LNT) model (Figure 5). Under this model, there is not a level of radiation dose above zero in which a response does not take place, and the response increases proportionately to radiation dose received (Bushong, 2017). The LNT model theorizes that risk is directly proportional to dose – suggesting that the more radiation an individual is exposed to the greater their risk for an adverse response such as cancer. Cancers and genetic mutations are the most common types of late stochastic (probabilistic) somatic effects.

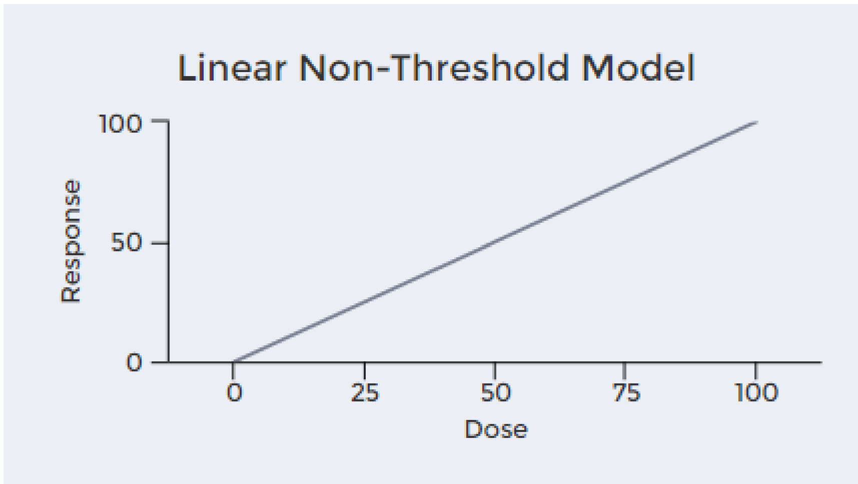


Figure 5. Linear non-threshold model (adapted from Gofman, n.d.).

Due to inconsistent study results, some researchers argue that the LNT model is not accurate in describing the relationship between radiation dose and cancer risk (Hendee & O'Connor, 2012). Other models on radiation effects are shown in relation to the LNT model in Figure 6. The exponential model theorizes that low levels would cause little to no harm, while higher doses would significantly increase risk (Gori & Munzel, 2012). The theory of hormesis, in which low levels of radiation are thought to be beneficial, would go against the LNT model's idea that any radiation dose above the natural occurrence could increase cancer risk (Bushong, 2017). In the stochastic model, the association between radiation dose and cancer risk is random. Though these models have been used to describe stochastic effects, the LNT model is currently the most widely accepted for radiation safety and protection practices.

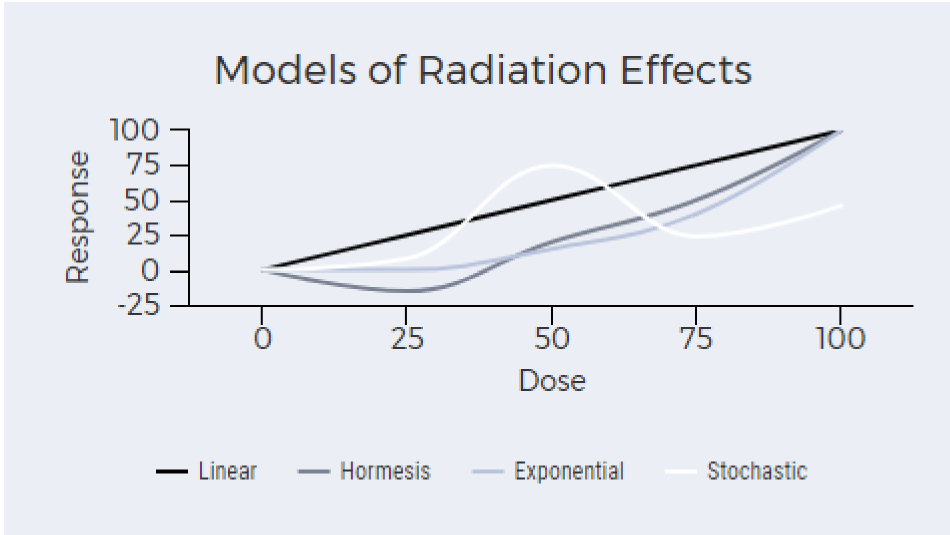


Figure 6. Models of radiation effects (adapted from Gori and Munzel, 2012).

Increasing Medical Radiation Dose

Since the 1980s, medical radiation dose has significantly increased. Today, an estimated 48% of the population's overall cumulative radiation dose is attributed to diagnostic imaging (NCRP, 2009). Much of this increase has been attributed to the rapid changes in CT technology and increase in CT examinations. Use of CT has skyrocketed from about 3 million examinations in 1980 to 62 million in 2006 in the U.S. alone (NCRP, 2009). The Food and Drug Administration (FDA) estimates that 20%-50% of "high-tech" medical examinations, in which CT scans were included, were not necessary in the diagnosis and treatment of the patient (FDA, 2017). While CT contributes the highest dose overall (47% cumulative dose), diagnostic radiographs are still the most performed medical imaging examination accounting for 74% of examinations (United Nations, 2008; Mettler et al., 2009). These diagnostic radiographs contribute an average 11% of the cumulative dose (NCRP, 2009).

One concern with increased radiation dose is an elevated risk of radiation-induced cancers later in life. Since cancers can spontaneously occur and most radiation induced cancers have such a long latent period (e.g., over 10 years past time of exposure), it is difficult to pinpoint which cancers are radiation-related. The National Research Council to Assess Health Risks from Low Level Ionizing Radiation estimates that 1 out of every 100 cancers could be related to an increase of 0.01 mSv over natural background radiation dose (National Research Council, 2006). The FDA estimates that an individual's risk of developing cancer from a single CT examination is 1 in 2,000 (FDA, 2017). The National Cancer Institute (NCI) suggests that up to 29,000 future cancers annually could be related to CT examinations (Berrington de Gonzalez et al., 2009). Some researchers argue that this number may actually be larger, but it is difficult to determine which cancers occur from radiation exposure as opposed to those that would naturally occur otherwise.

Studies on radiation workers and radiologic technologists have found that these populations have a higher rate of cancer than the general population and that these rates may be attributable to their increased work-related radiation dose. In 2002, a study was conducted on over 146,000 radiologic technologists and discovered that these individuals had a higher rate of breast cancer and leukemia (Mohan et al., 2002). A 2005 study examined a national sample of nuclear radiation workers with an average cumulative radiation dose of 19.4 mSv during the length of their employment and discovered they had between three and six times greater risk for all cancers compared to survivors of the A bomb (Cardis et al., 2005). These findings can be applied to the general patient population in that increased cumulative radiation exposure, even in small doses, can lead to increased cancer risk.

Cumulative Dose

Not only are radiation-based medical imaging procedures being ordered more often, but many individuals are receiving multiple radiologic examinations over their lifetime. A 2001 study found that 30% of patients in the study had over 3 CT scans, 7% had over 5 CT scans, and

4% had over 9 listed in their medical history (Wiest et al., 2002). A 2009 retrospective study found drastically increased results compared with the study by Wiest et al., with 33% having over 5 CT scans and 5% having over 22 CT scans in their medical history in the previous 22-year period (Sodickson et al., 2009). Due to the increasing use of medical imaging, upwards of 4 million individuals in the United States exceed 20 mSv annually (Fazel et al., 2009).

Dose Creep

Dose creep is a phenomenon in computed and digital radiography in which patient exposure increases over time. This occurs when the radiologic technologist selects a slightly higher technique containing more mAs than necessary in an effort to decrease image noise and the number of repeated examinations (Herrmann et al., 2012). The term mAs is a measure of radiation (milliamperage) over a period of time (seconds). Due to the ability to manipulate the image factors after exposure in digital radiography, many technologists familiar with the visual elements that appear in film radiography for under- and over-exposed images are not fully aware that these visual elements do not apply to digital imaging - making it difficult for the technologists to determine appropriate image quality.

An example of this phenomenon is shown below in Figure 7 and Figure 8. The images in Figure 7 were both obtained using 60 kVp and 4 mAs as the technique. The term kVp is a measure of the highest voltage of energy applied to the x-ray tube during radiation production. For reference an average technique for an anterior to posterior (AP) portable chest radiograph is 110 kVp and 1.7 mAs (Bontrager, 2002). It is evident in the image on the left using traditional film that the image is overexposed, however the image on the right visually appears within a normal exposure range for the digital image.

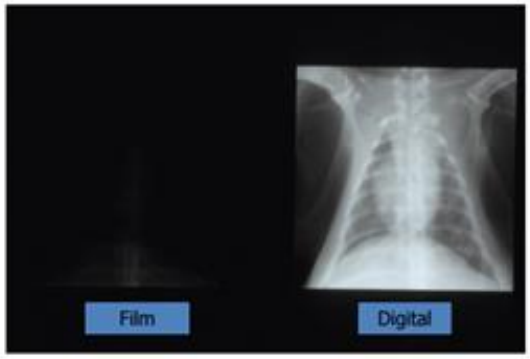


Figure 7. Dose Creep Film vs. Digital Exposure (Cooper, Cohen, Piersall, & Apgar, used with permission, 2009)

The images in Figure 8 were both obtained with a digital radiography system using 60 kVp. The difference is that the image on the left used 0.1 mAs and the image on the right used 128 mAs. Even though the image on the right used an exponentially higher dose, the images appear nearly identical. This lack of visual difference can lead to a technologist selecting a technique this is much higher than necessary to capture the diagnostic image and to the patient receiving a radiation dose higher than necessary to obtain the image.

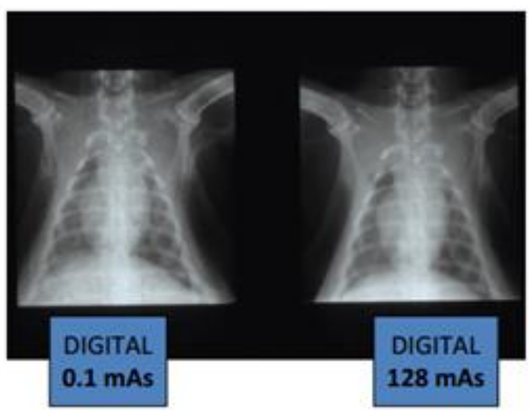


Figure 8. Dose Creep Digital Exposure with Different Technique (Cooper, Cohen, Piersall, & Apgar, used with permission, 2009)

In a longitudinal study by Gibson and Davidson (2012), researchers reviewed images for evidence of dose creep over a 28-month period. They found that this phenomenon occurred at the study site, and an intervention in which the radiologic technologists tracked the exposure index values for all chest x-rays resulted in less dose creep (Gibson & Davidson, 2012).

Organizations Overseeing Public Dose

There are multiple organizations that oversee the public's limit on radiation exposure dose. These include the International Commission on Radiation Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), and the Food and Drug Administration (FDA). These organizations set what is considered a "safe" annual effective dose limit for the public based on current literature while still maintaining limits in alignment with the concept of ALARA – "as low as reasonably achievable" –due to unknown effects of radiation exposure. Recommendations for annual effective dose limits for the public are updated as new discoveries are made about the effects of radiation on the human body. Organizations such as the FDA also use this information to set standards for radiation emitting equipment, including medical imaging equipment.

Medical Imaging Dose Reduction Methods

Early recommendations for radiation protection were loose compared with today's standards. Wolfram Fuchs was the first documented individual to recommend radiation protection methods in 1896, a year after the discovery of x-rays (ICRP, 2009). His recommendations were 1) limiting exposure time, 2) not standing within 12 inches of the X-ray tube, and 3) coating the skin with Vaseline. His suggested methods to decrease radiation exposure evolved over the years and eventually lead to the concept of "as low as reasonably achievable".

The main dose reduction principle in radiation physics is the concept of keeping patient dose ALARA. This implies that physicians and technologists administering radiation should take every measure to decrease patient dose as long as it does not interfere with the quality of the image or obstruct the anatomy of interest. The three cardinal rules to achieve ALARA are time, distance, and shielding (Bushong, 2017). Patients should have the lowest radiation exposure time allowable while maintaining image quality, should be positioned as far from the primary beam as possible, and should have external shielding measures applied so long as they do not interfere with the visualization of the anatomy of interest.

Many studies have focused on decreasing unnecessary examinations involving radiation in favor of non-radiation alternatives such as ultrasound and magnetic resonance (MR) imaging and the implementation of dose protocols specific to patients' size and age. Current X-ray and CT imaging equipment have built-in low dose protocols for pediatrics and safety measures such as x-ray tubes that lock into position at acceptable distances to receptors and in-house shielding. One factor that has been overlooked and is largely dependent on the technologist conducting the procedure is the use of secondary shielding through lead-equivalent shields during general radiography and lead or bismuth shields in CT examination performance.

Individuals in the public are often unaware of the average radiation dose for different medical imaging examinations. A study by Lee et al. (2004) found that only 3% of patients surveyed believed they were at an increased risk for cancer from a CT scan. The results of a study in Vermont revealed that 80% of participants underestimated the role medical imaging plays in contributing to overall radiation dose to the public (Evans et al., 2015). Additionally, the public may not be aware that they can and should be shielded during many of their radiologic examinations. In the same Vermont study, only one third of participants responded that they received education about the risks of medical radiation examinations from their healthcare provider (Evans et al., 2015).

Even individuals who work within a medical facility that has general radiography and CT are not fully aware of doses for each examination. In the same study by Evans et al., 47% of radiologists and a mere 9% of emergency room physicians thought CT increased the risk of cancer. Other studies have found similar results with physicians having low knowledge of the risks of radiation and many underestimating the radiation dose a patient receives from many common procedures (Krille et al., 2010). Shockingly, between 4% and 28% of physicians across these studies in Krille et al.'s (2010) systematic review responded incorrectly that ultrasound and MR imaging procedures emitted radiation. This lack of knowledge by healthcare providers may lead to increased use of radiation emitting procedures and contribute to the increased risk of radiation-induced cancers in the public.

Dose Reduction Campaigns

Due to the increased use of medical imaging modalities and the growing body of research on the health effects of increased radiation to the public, two campaigns have been created with the goals of raising awareness and providing educational material to individuals prescribing, administering, and receiving radiation emitting medical examinations. These campaigns provide information to physicians, technologists, and the general public on radiation safety in medical imaging. Healthcare providers and the general public can "pledge" to create a conversation around medical imaging dose to raise awareness or to implement changes within their workplace to decrease patient dose.

The *Image Gently* campaign is a coalition of multiple organizations including the Society for Pediatric Radiology (SPR), the American College of Radiography (ACR), the American Society of Radiologic Technologists (ASRT), and the American Association of Physicists in Medicine (AAPM). The campaign was launched in 2007 with the purpose of raising awareness and providing education about medical radiation safety to physicians, radiologic technologists, healthcare workers, and patient families in an attempt to decrease the amount of medical radiation children receive. *Image Gently* strives to have pediatric examinations justified and radiation protection methods applied at all times possible on those justified procedures.

Image Wisely is a collaboration between the ACR, the Radiological Society of North America (RSNA), the ASRT, and AAPM. The purpose of this campaign is to provide scientific-based information in an attempt to decrease the number of unnecessary radiologic examinations on adults and to lower the dose on those examinations that have been justified. A unique aspect of the *Image Wisely* campaign is an online feature for dose guidelines based on the specific brand of medical imaging equipment. This would allow facilities and employees to access information on dose reduction features on the equipment at their facility.

While both campaigns touch on the benefits of the use of shielding, most of the effort is focused on the reduction of unnecessary medical imaging examinations and the implementation of low dose radiographic techniques. Both of these methods have been shown to reduce overall patient dose; however, by adding appropriate shielding, the dose to radiosensitive organs can be reduced by up to 95% in radiography and up to 65% in CT (Health Physics Society, 2015; Morford & Watts, 2012). Additionally, while both provide free education via the internet, it is up to the healthcare worker, patient, or member of the public to access the materials.

Radiation Protection

Technologists' Role

Medical imaging technologists play an important role in radiation protection and patient dose reduction. These individuals are oftentimes the only employees within the medical imaging department that have direct contact with the patient. It is the technologist's duty to apply all measures available to them to reduce patient dose while maintaining image quality. The accrediting board for radiography and CT technologists, the ARRT, targets the technologist's role in 3 of the 10 responsibilities listed in the ARRT Code of Ethics:

1. The radiologic technologist assesses situations; exercises care, discretion, and judgement; assumes responsibility for professional decisions; and acts within the best interest of the patient.
2. The radiologic technologist uses equipment and accessories, employs techniques and procedures, performs services in accordance with an accepted standard of practice, and demonstrates expertise in minimizing radiation exposure to the patient, self, and other members of the healthcare team.
3. The radiologic technologist practices ethical conduct appropriate to the profession and protects the patient's right to quality radiologic technology care.

Additionally, in the ARRT Rules of Ethics, it is can be concluded that by not providing appropriate radiation protection, the radiologic technologist is engaging in unprofessional conduct as defined by the ARRT (ARRT, 2015). Rule 6ii of the ARRT Rules of Ethics prohibits "engaging in unprofessional conduct, including, but not limited to: any radiologic technology practice that may create unnecessary danger to a patient's life, health, or safety."

While the ARRT Rules of Ethics are enforceable, the Code of Ethics is not. Even so, the likelihood of reporting lack of patient radiation protection in the form of shielding and enforcement of repercussions, such as work suspensions or license revocations, to the technologist is low unless serious harm occurred to the patient that was evident at the time of treatment, as would be the case in delivery of high doses of radiation and a patient receiving radiation burns. This occurred in 2008, when a 23-month-old received 151 CT scans during a period slightly more than an hour and an estimated 2,800 mSv of radiation (Domino, 2010).

This event was not reported by the hospital as required, but by the parents who became concerned at the amount of time the CT procedure took and the burns that appeared on the child shortly afterwards. The CT technologist was eventually terminated and had her license revoked by the state of California and the ARRT. Even in this situation, the hospital did not report the issue immediately, which makes the reporting of lesser radiation protection infractions, such as lack of shielding, much less likely.

Radiography

In order to prevent excessive variation in procedure techniques and to best meet the cardinal principles of time, distance, and shielding, many radiation safety factors have been implanted within radiography equipment and software. This includes techniques set to have the lowest possible time, automatic exposure controls (AEC) to decrease time, and x-ray tube housing that locks into standard image receptor (IR) distances. Shielding can be achieved through tight collimation of the primary x-ray beam, placement of shadow shields, and the use of contact shields or lead aprons – all of which are dependent solely on the operating radiologic technologist. Shielding should be applied to every patient where radio-sensitive organs lay adjacent to the primary beam as long as the shield does not interfere with the primary anatomy being imaged (Herrmann et al., 2012).

In a 2010 study of radiologic technologists' safety practices in California, researchers found that many were conducting poor radiation safety measures for patients (Reagan & Slechta, 2010). Reagan and Slechta (2010) found that for gonadal shielding, 92% of those surveyed would always shield a 3-year-old male for a chest x-ray; however only 62% of participants stated the same for a 37-year-old male for a knee x-ray. Similarly, in a 2011 national study on technologist radiation exposure practices, 79% of participants reported witnessing another technologist not applying shielding measures when appropriate (Johnston, Killion, Vealé, & Comello, 2011).

A study on radiologic technologists in Australia found multiple factors affected the likelihood of technologists' use of shielding (MacKay, Hancy, Crowe, D'Rozario, & Ng, 2012). These included level of education, gender of patient, availability of shields, workplace shielding protocol, self-perception, and anatomy of interest. Shield use increased with level of education and awareness of shield location. Another 10 workplace factors were examined which ranged from "too busy" to "infectious patient" to "infertile patient". The likelihood of shield use in these situations ranged from 3.2%-96.9%. The technologist's fear of obscuring the anatomy and uncooperative patients were the two environmental factors in which the technologist was the least likely to use shielding.

Computed Tomography

As with radiography, CT has many equipment safeguards and often facility-implemented protocols to reduce patient radiation dose. Some of these methods are low dose protocols, AEC, and beam shaping filters. Lead-equivalent shields are often available to wrap around patients to protect reproductive organs during CT examinations. Bismuth shields are also available in some facilities to provide additional protection to radiosensitive organs such as eyes and breast tissue. Again, the use of these shields is left to the CT technologist's discretion.

A literature review by Morford and Watts (2012) found that dose to radiosensitive organs was decreased in all CT studies where bismuth shielding was implemented with a 39%-65% decrease to eyes, 42%-57% to thyroid, 26%-29% to breast tissue, and up to 53% to gonads. Similar results have been found when using lead shielding on radiosensitive organs that are not within the primary x-ray beam during an examination. Using lead shielding during head CTs resulted in an average 45% and 76% dose reduction for thyroid and breast, respectively

(Beaconsfield, Nicholson, Thornton, & Al-Kutoubi, 1998). These results show that shielding is an important factor for reducing patient dose during CT and should be used during exams where shielding would not interfere with the anatomy of interest, even if the radiosensitive organs are not within the primary beam.

With CT as the largest contributor to the population's annual medical radiation dose, it is important for all measures possible to be applied to decrease the dose a patient receives, including the application of shielding devices. In a national survey, Slechta and Reagan (2008) found that 22% of CT technologists surveyed reported never applying gonadal shielding on women of child-bearing age for a CT chest examination. Johnston et al. (2011) found less favorable results, with a mere 29% of CT technologists indicating using all dose reduction measures available at their facility – including shielding.

Safety Culture in Healthcare

Many healthcare organizations are moving towards a "safety culture". Healthcare groups are realizing that various factors, such as mistakes or treatment delays, during care can have a negative effect on patient health outcomes. This includes medical errors and shortcuts which may be related to increased workload, decreased number of employees, lack of education, and lazy organizational culture. Largely, the focus is on issues that cause harm to the patient in that current moment – fall risk, medication errors, and surgical errors. The purpose of these safety cultures is to maintain the best treatment and safest environment for members of the public who visit that facility for care. Safety cultures greatly improve the public's health by minimizing adverse outcomes from hospital stays and procedures.

Many medical errors may be underreported as an average of 52% of respondents in the Hospital Survey on Patient Safety Culture reported zero safety events in the previous 12-month period (Sorra, Famolaro, Dyer, Nelson, & Khanna, 2008). Radiation errors such as multiple exposures may be underreported less often than an exposure on the wrong individual or radiation of a fetus (National Radiation Laboratory, n.d.). A report on a medical radiation incident program in England received 968 notifications during a 1-year period, of which 81% were related to incidents in diagnostic radiography. Of the incidents reported in radiology, 50.7% were listed as operator or administrator error (Care Quality Commission, 2014).

It is difficult to see the issues from radiation exposure in real-time since the health problems do not manifest until many years later. This factor may contribute to why technologists have been observed not implementing all radiation protection methods to patients during examinations. However, it is considered the responsibility of employers and employees to establish and promote a culture of safety in radiology departments as organizational culture is difficult for larger agencies to regulate (HPS, 2012). It is important that all individuals within the radiology department have input on how to best transition their department to a "safety culture" (Cheung, 2013). The International Atomic Energy Commission (IAEC) and World Health Organization (WHO) list the development of safety cultures in medical radiation as one of 10 actions to improve medical radiation protection (IAEC and WHO, 2013).

Theoretical Framework

Social-Ecological Model

The theoretical framework for this study was the Social-Ecological model. This model has been used to describe how an individual's environment affects their behaviors. The ecological model was originally described by Urie Bronfenbrenner in the 1970s. Bronfenbrenner's ecological model was used to determine how social interactions and environment affected a child's development (Bronfenbrenner, 1979). The levels of

Bronfenbrenner's model include microsystem, mesosystem, exosystem, macrosystem, and chronosystem (Figure 9). This model has been adapted to public health settings to explain the associations between social interactions, environment, and an individual's health behaviors. The public health adaptation of the model defines the levels as individual, interpersonal, organizational, community, and public policy.

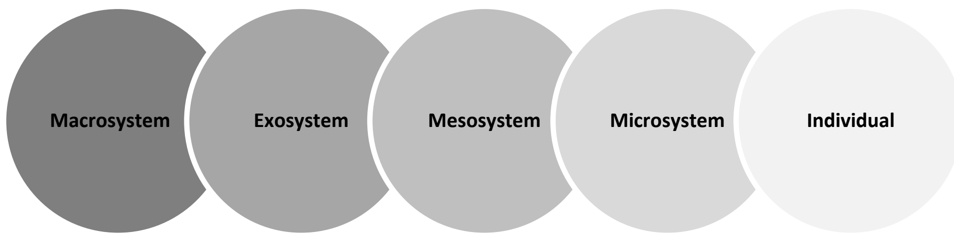


Figure 9. Ecological model (adapted from Bronfenbrenner, 1979).

<u>Applications</u>

The Social-Ecological model has been used in community settings to determine barriers to numerous health related factors. This includes, but is not limited to, breastfeeding, vaccinations, cancer screening, and HIV testing (Dunn, Kalich, Henning, & Fedrizzi, 2015; Kumar et al., 2012; Ferrer, Trotter, Hickman, & Audrey, 2014; Holden, Strazza-Moore, & Holliday, 1998; Naar-King et al., 2013). The model has also been applied to occupational stressors (Salazar et al., 2000). A recent article also describes the Social-Ecological model's application to community needs assessments (Brown, 2015).

<u>Applying Social-Ecological Model to Medical Imaging</u>

Nearly all radiologic technologists currently working in the field of radiology received education and training on the use of shields through their certificate or degree program. The main radiographic positioning textbooks, such as *Merrill's Atlas of Radiographic Positioning and Procedures* and the *Textbook of Radiographic Positioning and Related Anatomy*, used in many radiologic technology educational programs, repeatedly state the use of shields on all examinations as long as they do not interfere with the anatomy of interest. Even with this educational background, the small pool of research on shield use shows that the application of shields by technologists during clinical practice is low. This leads to the hypothesis that a factor other than education plays a significant role in the technologist's use of shielding for the patient. The Social-Ecological model can be used to determine factors at each level and the role these factors play with shield use.

Summary

Shield use during medical imaging procedures is one of many important factors in keeping patients' radiation dose as low as possible. While there is little literature on patient shielding rates, a small amount of research shows that shields are not being applied during all instances when applicable. The reasons behind barriers to shield use are still not fully known in radiologic technologist populations in the United States. This literature review shows that there is still pertinent information needed to understand why technologists are not shielding in order to develop interventions to increase shield use.

CHAPTER 3

METHODS

Introduction

This study was completed in two phases. Phase 1 involved the development of a moderator guide and conducting focus groups to collect qualitative data from registered radiography and CT technologists to develop a quantitative survey instrument (Phase 2). Phase 2 consisted of a pilot test of the survey instrument, national dissemination of the instrument, and analysis of the quantitative data.

Procedures

The following procedural steps were conducted to address the two study aims:

1. Qualitative data collection with local radiologic and computed tomography technologists from the Tri-Cities region of northeast Tennessee to lead to survey development.
2. Development of survey items from results of qualitative analysis.
3. Pilot testing of survey instrument to determine study completion times, response rate, reliability, and validity.
4. Administration of a the survey to a national sample
5. Analyses to explore associations between the dependent variable of shield use and independent variable levels of intrapersonal, interpersonal, organizational, and community.

Phase 1: Qualitative Design

Study Design

Grounded theory was used to explore themes in shielding beliefs, attitudes, practices, and environment. The development of this research method has been credited to the work produced by Anselm Strauss and Barney Glaser. Strauss and Glaser developed the methods of grounded theory while working together on research about experiences with dying and later published *The Discovery of Grounded Theory* in 1967 (Birks & Mills, 2015). This type of qualitative data analysis is beneficial for topics with little previous research and understanding as it is used to start from a beginning question and gain insight through themes in the data. It was determined that this type of analysis would be best since the review did not reveal previous literature in relation to technologist shielding behavior and Social-Ecological levels.

The East Tennessee State University (ETSU) Institutional Review Board (IRB) approved the focus group informed consent, moderator guide, and recruitment flyers on August 16, 2016.

Moderator Guide Development

The focus group moderator guide was developed through review of the literature and with a panel of experts in the field of medical imaging. These individuals included a Radiologic Program Director from the Cambridge Institute of Allied Health in Georgia, a Radiographic Technology Department Chair from the West Georgia Technical College, and a medical imaging department manager from the Wellmont Health System in Kingsport, TN. Individuals were asked to provide questions for the moderator guide on technologists' radiation knowledge, shielding practices, and barriers and facilitators to shielding. These panel members emailed the investigator questions in June 2016. A total of 66 questions were submitted for review. The investigator compiled all submitted questions and ranked each question (1 = least important, 5 = most important) in regards to how important the question was in exploring the topic of shield use. After ranking, the investigator selected 47 questions to be used in the moderator guide. These questions were reworded with the help of the dissertation chair and committee for participant clarity. The final version can be viewed in Appendix A.

Focus Group Moderator

A moderator was selected to facilitate the focus groups. The investigator believed that it was best to have a separate individual conduct the focus groups to decrease social desirability of responses. This was an individual who had a background in both medical imaging and public health. The investigator had known and worked closely with this individual for 10 years prior to this study and felt this individual would be a good fit to conduct the focus groups.

Participant Recruitment

Flyers were posted at local medical facilities after approval was obtained by facility managers. These facilities included hospitals, clinics, and outpatient centers within the Tri-Cities region (Johnson City, Kingsport, and Bristol) of Tennessee. The investigator traveled over a period of 1 week during August 2016 to post flyers. A total of 14 facilities were visited and over 20 flyers were placed in various high traffic areas within these facilities. The flyer can be viewed in Appendix B.

A total of 9 participants contacted the investigator via phone. Contact information was collected from these individuals and stored in a password protected excel file. These individuals selected 1 out of 2 dates in September 2016 to participate in the focus group. Two emails were sent to each participant to remind them of the upcoming focus group, one 2 days prior to and the other on the morning of their scheduled focus group. Of the 9 interested participants, 7 attended the focus groups.

Participant Compensation

Participants were compensated $20.00 for their time. Compensation was provided in the form of cash after completion of the focus group. Each participant signed the ETSU Research Participant Payment Verification Form.

Data Analysis

Data analyses of the focus groups occurred in October 2016. Both focus groups were audio recorded and then transcribed verbatim by the investigator. Constant coding was used to develop codes, categories, and themes for the data collected. The investigator developed the codes after review of the typed transcriptions. Transcripts were then reviewed separately by the investigator and the focus group moderator to assign the codes to the transcribed data. Together the investigator and moderator developed categories for the codes. The investigator then reviewed the categories and developed themes that were related to the coded categories.

Phase 2: Quantitative Design

The survey instrument was designed through review of the literature and the information gathered from the focus groups (Phase 1). The survey instrument was modified after data analysis from the pilot study. The final survey instrument can be seen in Appendix C.

Initial Survey Development

The survey instrument was developed from the themes identified from the focus groups. Survey items were developed by the investigator with guidance from the dissertation committee. These items were categorized into the 5 levels of the Social-Ecological model. The final instrument consisted of 8 sections: demographic (5 items), personal work behavior (7 items), intrapersonal (13 items), interpersonal (17 items), organizational (5 items), policy (3 items), and community (6 items). An additional section of 9 CT modality specific items were included for those who considered this their primary modality. This survey instrument was approved by the ETSU IRB on November 28, 2016.

Survey Measures

Survey items were created using Likert-type response scales with the intention of performing logistic regression; however, due to incidence of similarity within response survey item categories, this analysis could not be conducted. Instead item responses were combined for each Social-Ecological level creating scales. These new combined scales were used for multiple regression analyses.

Scoring Survey Items

Survey items were created in Likert-type scales for participant completion. Those responses were then calculated into scores for each socio-ecological level in order to perform Pearson's correlation and linear regression. Each survey item had 1 of 5 response choices (agree/disagree and always/never format) which were then scored with a 1 to 5 depending on the response (example: always=5). Survey items for each Social-Ecological level were then able to be grouped to form a combined score for each level.

For example, the survey contained 3 items related to the community level of the Social-Ecological model. Depending on participant response, the combined score for these 3 items could range from 1-5. If a participant answered agree to all 3 questions it resulted in a combined score of 4 for the community level.

Pilot Study

Participant Recruitment

The investigator submitted a request to the ARRT for a sample of 1,707 individuals from their membership mailing list. This sample contained technologists registered in radiography (50%) and CT (50%). A sample of 40 individuals was randomly drawn from the ARRT supplied list. An email including the link to survey instrument was emailed to these individuals for participation in May 2017. A reminder email was sent 1 week after the initial email.

These individuals were ineligible to participate in the national survey due to their involvement in the pilot test.

Participant Compensation

Individuals who completed the pilot test were asked to provide their email address if they would like to be included in a drawing for 1 of 2 iPads. These emails were not linked to participants' survey responses for confidentiality reasons.

Factor Analysis and Reliability

Exploratory factor analysis was performed on pilot study data to modify the original survey instrument. This was done by creating reliable and valid scales for each of the Social-Ecological levels through factor analysis and Cronbach's alpha analysis. Those items that had a factor loading of .7 or greater were included in the national survey instrument. Cronbach's alpha was used to test the reliability of those items that met the factor loading of ≥.7. These analyses allowed the investigator to include survey items that had the most reliable predication of the social-organizational level being measured.

Survey Instrument Revision

Guided by the results of the pilot study, the survey instrument was revised to create a more concise instrument. This revision removed the Social-Ecological level of policy due to the lack of items that met the factor loading criteria. The revised document was submitted to the ETSU IRB and was approved September 1, 2017.

National Survey

Sampling Frame

The national survey sampling frame was a list of technologists registered in and primarily working within the modalities of radiography (50%) and CT (50%). The sample for the national survey was obtained by the investigator in March 2017 through a request to the ARRT for a sample from their membership mailing list. Technologists affiliated with the ARRT are able to choose to have their contact information available on this membership mailing list. The ARRT provided a random sample of the requested 1,707 individuals. Forty of the individuals were used for the pilot study leaving 1,667 available to contact for the national survey.

Due to the academic nature of this study, the ARRT provided the sample to the investigator at free of charge. The list was provided via email in an excel file which was password protected.

Sample Size Estimation

The following formula was used to calculate sample size for this quantitative survey: $n = Z^2pq/d^2$ (Bartlett et al., 2001). For this study, the alpha was set at 0.5, giving a Z score of 1.96. The confidence level set at 95% and d = 0.05 represents the margin of error set for this study. Considering the lack of evidence in the literature on the prevalence of technologist shielding behavior, the probability is set at 50%. This formula is calculated in Table 1.

Table 1.
Formula for Sample Size Estimation

Equation
$n= (\alpha)^2(p)(q) / (d)^2$
$n= (1.96)^2(0.5)(0.5) / (0.05)^2$
n= 0.9604 / 0.0025
n= 384.16

Note. n = sample size; α = confidence level 95%;
p = probability 50%; q = 1-p = 50%; d = margin of error 5%.

To control for sampling error the following non-response rate was calculated (Table 2). An average 30% non-response rate was used for this formula derived from the response rate noted in the literature with similar populations. This resulted in an increase of 115.248, resulting in a sample size of 500.

Table 2
Formula Controlling for Sampling Error

Equation
n= sample size + (sample size x anticipated response rate)
n= 384.16 + (384.16 x 0.30)
n= 384.16 + 115.248
n= 499.408

In order to obtain the 500 responses required to meet the 95% confidence level a total of 1,667 individuals were contacted to participate in the national survey. This is shown in the formula below (Table 3).

Table 3.
Formula for Complete Sample Required

Equation
n= sample size / anticipated response rate
n= 500 / 0.30
n= 1,666.66667

Participant Recruitment

The remaining 1,667 eligible participants from the ARRT membership mailing list were contacted via email in September 2017. The email contained information about the survey instrument and a link to the revised survey though the online site Survey Monkey. The survey was open for a total of 2 weeks. Participants received 2 reminders emails, one 5 days and one 10 days after the initial contact email was sent.

Participant Compensation

All participants had the opportunity to submit their name, email, and phone number to be entered into a drawing for 1 of 2 iPads. This information was voluntary and not linked to the individuals' survey responses.

Data Analysis

Survey Analysis

Data were exported from the Survey Monkey website in SPSS format. These data were analyzed in SPSS version 20 (SPSS IBM, New York, USA). Participants who did not complete the majority of the survey were removed before analysis (n=47). This included participants who did not complete the behavior section and at least 2 of the 4 Social-Ecological level sections.

Descriptive Analysis

Participant demographics were analyzed with descriptive statistics (means and percentages). These analyses were conducted separately for each modality to allow for comparison.

Factor Analysis and Reliability

Factor analysis was conducted on the survey items. Items with a factor loading of .5 or greater were selected for inclusion into a scale. This factor loading level was determined due to low response rate, exploratory nature of the study, and committee recommendation. Items within the factor loading level were then grouped into Social-Ecological levels (intrapersonal, interpersonal, organizational, and community). Shield availability was conducted separately from organization during this analysis due to the different response type. A reliability analysis was conducted on these scales to determine the Cronbach's alpha for each of these Social-Ecological levels. Those scales with a Cronbach's alpha >.70 were considered to be reliable in representing those levels.

Bivariate Analysis

Spearman's correlation was used to determine associations between the dependent variable (shielding behavior score) and individual items before they were grouped into ecological levels. Statistical significance was fixed at $p<.05$.

Pearson's correlation was then conducted to determine the association between the dependent variable (shielding behavior score) and the independent levels (intrapersonal, interpersonal, organizational, and community). Modalities were separated to examine differences between radiologic and CT technologists. Statistical significance was set at $p<.05$.

Multivariate Analysis

Multiple linear regression was conducted for the dependent variable (shielding behavior score) and each of the 4 Social-Ecological levels independently. For each Social-Ecological level, 3 different models were examined, non-adjusted, adjusted for technologist characteristics, and adjusted for modality history. Cases were separated into modalities prior to conducting multivariate analysis to examine variances between the two groups (Radiologic and CT). Statistical significance was set at $p<.05$.

CHAPTER 4

RESULTS

Introduction

The results are divided into two categories: Phase 1 and Phase 2. As the matter of technologist use of shielding in the reduction of patient radiation has not been widely studied, the investigator collected both qualitative and quantitative data to best understand the issue. During Phase 1, the investigator conducted focus groups to identify any contributing factors to shield use that had not been previously mentioned in the literature. The data from Phase 1 led to the thematic analysis of the data and development of survey items and an instrument used in Phase 2. In Phase 2, the investigator piloted and modified the survey instrument, administered the survey instrument nationally, and performed descriptive, bivariate, and regression analyses on the data.

Phase 1: Qualitative Study Results

Seven registered radiologic technologists participated in the focus groups; of these, 3 considered diagnostic radiography their primary modality, 3 considered CT their primary modality, and 1 considered ultrasound their primary modality but had recently spent multiple years working in CT. The backgrounds of the participants varied and included recent graduates, individuals working in the field 5-10 years, hospital employees and clinic employees.

Six themes arose from the focus groups. These themes included: 1) Workplace facilitators, 2) Workplace barriers, 3) Peer influence, 4) Patient condition, 5) Conflicting information, and 6) Technologist desire to do best for the patient. A summary of these 6 themes is provided below.

Theme 1: Workplace Facilitators

Though the participants' backgrounds and current employment environments varied, all agreed that more understanding and appreciation from their organization would allow them to provide better care to their patients. Shield availability and locations were discussed as being a major facilitator as to whether or not they shielded and that shields placed within view of the examination room were a reminder to use them. Additionally, some mentioned that recognition and appreciation from their management team led them to want to do better for the department and the patient, this also included shield use. "Even if there was like 'good job on shielding'"

Theme 2: Workplace Barriers

Unlike workplace facilitators, participant discussion of barriers varied according to the type of facility in which they were employed. Many participants discussed difficulty with organizational constraints on time, staffing, and resources. The pressure to complete exams during a certain amount of time and lack of adequate staffing led to technologists feeling rushed and forgetting to shield. "If you had more staffing you would have more time to spend with each patient". Others reported that they did not feel they had the proper shields available to them, that they had to spend time hunting shields down in the department, and that occasionally they had to use their personal lead to shield their patients. "I work night shift and day shift moves things around, I can get in a room and there is no apron. So then I have to go find one and I can't leave my patient on the table".

Theme 3: Peer Influence

Participants agreed that seeing other technologists use shielding is a reminder that they need to apply shielding also. Many stated that their current shielding habits were directly related to the habits of the facility in which they worked – if many technologists did not shield, they themselves did not shield even if they agreed shielding was important. "If I see people around me shielding more it reminds me to be more on top of it (shielding) and do it more myself". Additionally, some participants expressed that coworkers often did not use shielding or feel it was necessary. In relation to how often they see others not shielding: "Every day" and "very often".

Theme 4: Patient Condition

All participants agreed that the condition of the patient was a crucial factor in their use of shielding. Participants discussed the pressure to complete examinations quickly either due to the critical condition of the patient, discomfort of the examination, and combativeness of some patients. There was consensus that during some of these situations shielding was the last factor on their mind and the end goal was to get the patient into a more comfortable environment where they could be cared for by other members of the medical team. "If they are very critical I don't want to waste extra time trying to shield when they could code at any minute". Another factor discussed by participants was the lack of shield use on patients who were in contact isolation status due to the fear of spreading disease to other patients. Some stated they would use shielding on patients in contact isolation "if they were easier to clean."

Theme 5: Conflicting Information

Surprisingly, although all the participants graduated from the same academic program, they had varying responses in relation to when to shield someone and how beneficial it was or not. Participants discussed that they had been told by many different resources (including management, radiologists, and ER physicians) conflicting information on shield use. This led participants to feel they lacked knowledge on when to shield and led to confusion. "I have had conflicting conversations with different physicians about shielding pediatrics, and that is, that's concerning because I don’t really know which way to go with it". Many stated that even within one facility that the radiologists provided conflicting information from another radiologist. "If that radiologist is reading, you shield, if that radiologist is not reading you don't shield because the other radiologist doesn't like it. We don't have a proper protocol."

Theme 6: Technologist Desire to Do What's Best for the Patient

Though all participants agreed that they felt stressed due to lack of resources and time constraints, there was constant discussion of how they wanted to be sure to provide the best care for their patients. Many felt that they had too much to perform at work in a short amount of time and that they would like to be able to spend more time practicing patient care to make the patient more comfortable during the examination. "Not that you want to not do a good job, you have to think about time, you know – getting your patient on the table, getting exams done, and getting to your other patients, because you know you can't leave them waiting".

Phase 2: Quantitative Study Results

Pilot Study

The purpose of the pilot study was to determine the following:

1. Response rate
2. Survey completion time
3. Instrument reliability and validity

Pilot Study Response Rate

Of the 40 individuals who were contacted to participate in the pilot study, 12 completed the survey instrument. This led to a 30% response rate for the pilot study which was higher than anticipated. Eight individuals (66.67%) considered CT and four individuals (33.33%) radiography their primary modality of employment.

Pilot Study Completion Time

Average completion time for the survey instrument was 11.5 minutes. Individuals spent between 2 minutes to 2 hours completing the survey. The survey time of 2 hours was removed from the calculation of completion time due to being an extreme outlier.

Pilot Study Instrument Clarity

Factor analysis was conducted on the pilot study data. This analysis is often used to explore data in new topics and to understand how survey items are associated with each other. Factor analysis uses the survey items and groups those items associated into factors. This allows a researcher to examine how many factors might be affecting a certain outcome.

The analysis revealed 12 items with a factor loading >.70 for the independent levels. No items met the factor loading criteria for survey questions related to policy levels. An additional 4 survey items related to the dependent outcome behavior of shield use met the factor loading criteria. Table 4 below describes the factor loadings for the pilot survey items.

Reliability testing was performed on these Social-Ecological level scales. The intrapersonal, interpersonal, organizational, and behavioral scales were found to be highly reliable with Cronbach's alpha of .927, .857, .928, and .984 respectively. The community and organizational shield availability levels were not found to be as reliable but this could have been attributable to small sample size (α=.585, .698 respectively).

With insight from the results of the factor analysis and item reliability, 21 survey items were removed from the original pilot survey instrument. This resulted in a total of 48 items included in the survey instrument for national administration.

Table 4.
Factor Analysis and Cronbach's α for Pilot Study

Social-Ecological Level	Item	Factor Loading	Cronbach's α
Intrapersonal	I believe I received adequate training on shield use while enrolled in my radiography program	.830	.927
	The use of shielding can reduce the patient's direct radiation exposure to radiosensitive organs.	.925	
	I believe it is important to shield patients in contact isolation.	.942	
	I am more likely to shield a family member or friend as opposed to a stranger.*	.845	
	Shielding patients is a waste of my time.*	.911	
Interpersonal	I would be more likely to use shielding if I were to see more technologists at my facility use shielding.	.892	.857
	I would be more likely to use shielding if I saw technologists who I am friends with use shielding.	.836	
	Shielding is important within the facility in which I work.*	.946	
	My co-workers shield all patients as long as it does not interfere with the examination.*	.753	
Organizational	I would be more likely to shield if management offered incentives for shielding.	.960	.928
	I would be more likely to shield if management reprimanded employees who were caught not shielding when they should.	.849	
	I believe a sign reminding me to shield would increase my use of shielding.	.891	
	Management stresses the importance of shield use to employees often.*	.825	
Shield Availability	Shields are easily within reach in the radiographic exam room.	.892	.698
	Use my personal lead apron to shield a patient.	.799	
	There are shields on the portable machines at my facility.*	.763	
Community	I often have patients who refuse to be shielded.	.878	.585
	Most patients are only aware of the medical radiation health risks in relation to pregnancy and/or reproduction.	.934	
	Patients do not think shielding is important.*	.826	
Behavior	Shield children under the age of 13 years old.	.964	.984
	Shield children between the ages of 13-18.	.953	
	Shield patients as long as the shield does not interfere with the anatomy of interest.	.892	
	Shield individuals that are of reproductive age (over 18 years but less than 55 years).*	.917	
	Shield pregnant women.	.908	

*survey item was removed for the resulting Cronbach's α

National Survey

Survey Response Rate

Two-hundred and sixty-five individuals responded to the national survey. After removing insufficient cases, a total 218 completed surveys remained for analyses. Again, those removed were cases in which the behavioral section and at least 2 of the 4 Social-Ecological sections were not completed. This resulted in an the overall response rate of 13%, which was lower than anticipated and lower than studies of similar populations in the literature.

Descriptive Statistics

Descriptive analysis revealed that the number of participants in each modality were nearly even, with 53.7% having a primary modality in CT and 46.3% in radiography. The mean age of CT technologists was 43 years and radiologic technologists 41 years. In both modalities the majority of respondents were female, Caucasian, and of non-Hispanic heritage. Most participants had been employed and registered in their primary modality for 15 years or less. Table 5 provides more detail on study participants.

Table 5.
Descriptive Participant Characteristics by Primary Modality, n=218

	Frequencies by Modality	
	Radiologic	**CT**
Technologist Characteristics		
Age in years	41 (mean) 24-65 (range)	43 (mean) 24-62 (range)
Gender		
Female	81.2%	65.8%
Male	18.8%	34.2%
Race		
Asian	2.0%	4.3%
Black/African American	8.9%	3.4%
Native Hawaiian/Pacific Islander	1.0%	0%
White/Caucasian	88.1%	92.2%
Hispanic heritage		
Yes	11.9%	5.1%
No	88.1%	94.9%
Modality History		
Years employed in primary modality		
0-5 years	30.7%	14.5%
6-10 years	30.7%	24.8%
11-15 years	11.9%	20.5%
16-20	9.9%	15.4%
21-25	4.0%	12.8%
26-30	5.0%	5.1%
31-35	4.0%	4.3%
36 years or more	4.0%	2.6%

Years registered in primary modality		
0-5 years	31.7%	21.6%
6-10 years	28.7%	28.4%
11-15 years	12.9%	14.7%
16-20	7.9%	15.5%
21-25	6.9%	8.6%
26-30	4.0%	6.0%
31-35	4.0%	2.6%
36 years or more	4.0%	2.6%

Analyses for Research Aim 1

Factor Analysis and Reliability Testing

Exploratory factor analysis was performed on all survey items. With guidance from the committee, factor loading index was set at .5 due to low response rate and the exploratory nature of the study. Of the 7 items related to the dependent variable of shield use behavior, 6 resulted at >.5. For the ecological levels, 3 intrapersonal items, 2 interpersonal items, 7 organizational items, and 3 community items met the index criteria. This resulted in a total of 21 out of the 30 survey items that were included in further analyses. These items were combined into their respective ecological level scale and tested for reliability. The Social-Ecological level scales of interpersonal, organizational, and the dependent grouping of behavior were found to have high reliability (α=.96, .83, and .90 respectively). The results of both the factor analysis and reliability testing can be found in Table 6.

Table 6.
Factor Analysis and Cronbach's α for National Study

Social-Ecological Level	**Item**	**Factor Loading**	**Cronbach's α**
Behavior	Shield children under the age of 13 years old.	.890	.900
	Shield children between the ages of 13-18.	.918	
	Shield patients as long as the shield does not interfere with the anatomy of interest.	.830	
	Shield individuals that are of reproductive age (over 18 years but less than 55 years).	.871	
	Shield pregnant women.	.759	
	Ask patients of child-bearing age if they could be pregnant.*	.566	
Intrapersonal	I am more likely to shield a family member or friend as opposed to a stranger.	.553	negative
	Shielding is an important factor in reducing cancer risk in patients.	.516	

	It is more important to shield a child than an elderly patient.	.807	
Interpersonal	I would be more likely to use shielding if I were to see more technologists at my facility use shielding. I would be more likely to use shielding if I was technologists who I am friends with use shielding.	.661 .691	.963
Organizational	I would be more likely to shield if management offered incentives for shielding. I would be more likely to shield if management reprimanded employees who were caught not shielding when they should. I believe a sign reminding me to shield would increase my use of shielding. Management stresses the importance of shield use to employees often.*	.715 .698 .536 .518	.832
Shield Availability	Shields are easily within reach in the radiographic exam room. There are shields on the portable machines at my facility. Use my personal lead apron to shield a patient.*	.752 .788 .625	.614
Community	Patients do not think shielding is important. I often have patients who refuse to be shielded. Most patients are only aware of the medical radiation risks in relation to pregnancy and/or reproduction.	.568 .721 .575	.505

*survey item was removed for the resulting Cronbach's α

Bivariate Analysis

Following factor analysis and reliability testings, a Spearman's correlation was conducted on each of the individual items that met the factor loading index criteria (>.50). When analyzed individually, 6 items were found to be significant in relation to shield use, 3 at the $p \leq .05$ levels and 3 at the $p \leq .001$ levels. Significant findings for this analysis can be found in Table 7.

Table 7.
Significant Spearman Correlation for Individual Items

Item	Spearman Correlation	t-test
I am more likely to shield a family member or friend as opposed to a stranger.	-.301**	p≤.001
Shielding is an important factor in reducing cancer risk in patients.	.343**	p≤.001
Management stresses the importance of shield use to employees often.	.377**	p≤.001
Shields are easily within reach in the radiographic exam room.	.149***	p=.024
There are shields on the portable machines at my facility.	.173***	p=.011
Patients do not think shielding is important.	-.204***	p=.002

**Significant at the p≤.001, ***Significant at the p≤.05

Pearson's correlations were conducted on the items after being combined into the ecological level scales (Table 8). Statistically significant differences were observed at the organizational level for technologists in CT ($r=.292$, $p<0.01$). Technologists whose primary modality was CT had higher organizational level scores than those technologists whose primary modality was radiologic technology (mean score 22.52 vs. 21.88, respectively). Significant differences between modalities were not found at the intrapersonal, interpersonal, and community levels.

Table 8.
Pearson Correlation for Ecological Levels, n=218

	Radiologic		**CT**	
	r	p	r	p
Intrapersonal	-.085	.399	-.037	.693
Interpersonal	-.147	.144	.151	.107
Organizational	.006	.954	.292**	.002**
Community	-.124	.216	-.097	.298

*Significant at p<0.01; p-values obtained from t-test

Analyses for Research Aim 2

Multivariate Analysis Results for Scored Social-Ecological Level

Multiple linear regression analyses were performed for each of the 4 Social-Ecological levels for both radiologic and CT technologists separately. Three different models were examined, unadjusted (1[a]), adjusted for technologist characteristics such as age and gender (2[b]), and adjusted for modality history to include how long the technologist has worked in their primary modality and how long they have been registered by the ARRT in their primary modality (3[c]). Results are described for each of the levels and models below in Table 9, Table 10, Table 11, and Table 12. A summary of significant models can be seen in Table 13.

Shielding score and intrapersonal level score

Intrapersonal level score was not found to be a significant predictor of technologist shield use in either modality. This finding remained unchanged in both the unadjusted model and the models adjusted for technologist characteristics and modality history. The results at this level suggest that intrapersonal beliefs may not be the best predictor of shield use. An intervention at this level may not provide the most efficient result in increasing shield use among technologists. This is described below in Table 9.

Table 9.
Multiple Linear Regression Analysis of the Association Between Shielding Behavior Score and Intrapersonal Level Score, n=216

	B (SE B)					
	Model 1[a]		**Model 2[b]**		**Model 3[c]**	
	Radiologic	CT	Radiologic	CT	Radiologic	CT
Intrapersonal score	-.120(-.085)	-.154(-.037)	-.076(-.053)	-.118(-.028)	-.076(-.054)	-.068(-.017)
Age			.008(.057)	.039(.088)	.006(.041)	.087(.198)
Gender			.521(.131)	-.741(-.081)	.559(.141)	-.591(-.065)
Years employed in primary modality					-.218(-.274)	-.060(-.025)
Years registered in primary modality					.241(.305)	-.227(-.095)

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history

Shielding score and interpersonal level score

Neither unadjusted nor adjusted models were found to be significant predictors of shield use on the interpersonal level. This result was found for both radiography and CT modalities. The lack of significance suggests that interpersonal factors may not greatly affect technologist shield use. Interventions at this level would likely not result in a large increase in shield use among medical imaging technologists. Results are shown in Table 10.

Table 10.
Multiple Linear Regression Analysis of the Association Between Shielding Behavior Score and Interpersonal Level Score, n=214

	B(SE B)					
	Model 1[a]		**Model 2[b]**		**Model 3[c]**	
	Radiologic	CT	Radiologic	CT	Radiologic	CT
Interpersonal score	-.132(-.147)	.390(151)	-.112(-.125)	.457(.177)	-.119(-.133)	.450(.177)
Age			.007(.046)	.050(.113)	.002(.017)	.102(.232)
Gender			.482(.122)	-.860(-.094)	.527(.133)	-.698(-.077)
Years employed in primary modality					-.235(-.297)	-.075(-.031)
Years registered in primary modality					.273(.347)	-.256(-.107)

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history

Shielding score and organizational level score

The model was statistically significant in the unadjusted model for technologists in the CT modality (F[7.836,18.750]=9.709, p<05, adj R^2=.077). When adjusted for technologist characteristics (age and gender), the model was again found to be statistically significant for technologists in the CT modality (F[.169,.651]=4.405,p<.01, adj R^2=.089). Results for CT technologists were also found significant in Model 3[c] when adjusting for modality history (F[.170,.646]=3.008, p<.01, adj R^2= -.088; Table 11). Unadjusted and adjusted models for technologists in the radiologic technology modality were not statistically significant at the organizational level.

The results of this analysis indicate that the organizational level is a significant predictor of shield use. An intervention at the organizational levels may be beneficial in increasing shield use among CT technologists in attempt to decrease radiation dose to radiosensitive organs.

Table 11.
Multiple Linear Regression Analysis of the Association Between Shielding Behavior Score and Organizational Level, n=195

	B(SE B)					
	Model 1[a]		**Model 2[b]**		**Model 3[c]**	
	Radiologic	CT	Radiologic	CT	Radiologic	CT
Organizational score	.003(.006)	.376(.292)*	.029(.057)	.410(.319)**	.029(.057)	.408(.323)*
Age			.015(.108)	.065(.140)	.011(.080)	.114(.245)
Gender			.714(.183)	-.938(-.098)	.765(.196)	-.770(-.082)
Years employed in primary modality					-.211(-.261)	-.104(-.041)
Years registered in primary modality					.251(313)	-.162(-.066)

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history; *Significant at p<.05; **Significant at p<.01

Shielding score and community level score

The community level was not found to be a significant predictor of technologist shield use. Neither unadjusted nor adjusted models were found to be significant in either modality.

This is shown below in Table 12. Interventions with the community would not provide the biggest impact to increase shield use during medical imaging examinations.

Table 12.
Multiple Linear Regression Analysis of the Association Between Shielding Behavior Score and Community Level, n=216

	B(SE B)					
	Model 1[a]		**Model 2[b]**		**Model 3[c]**	
	Radiologic	CT	Radiologic	CT	Radiologic	CT
Community score	-.121(-.124)	-.261(-.097)	-.135(-.139)	-.273(-.102)	-.132(-.136)	-.175(-.066)
Age			.008(.054)	.038(.087)	.006(.039)	.083(.188)
Gender			.630(.159)	-.821(-.089)	.660(.167)	-.648(-.072)
Years employed in primary modality					-.159(-.201)	-.070(-.029)
Years registered in primary modality					.182(.230)	-.185(-.078)

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history

Table 13.
Significant Multivariate Models for Combined Social-Ecological Levels

	B	SE B	CI (95%)	p-value
Behavioral score and organizational score model 1[a] for CT	.376	.292	.137-.616	.002
Behavioral score and organizational score model 2[b] for CT	.410	.319	.169-.651	.001
Behavioral score and organizational score model 3[c] for CT	.408	.323	.170-.646	.001

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history

Multivariate Analysis Results for Non-scored Social-Ecological Levels

Multiple linear regression was then performed on individual survey items that comprise the Social-Ecological level, as opposed to a combined score for those items, to examine which items may have significant findings. The results are shown for each of the Social-Ecological levels separately in Table 14, Table 15, Table 16, and Table 17. Significant results from all levels can be seen in Table 18.

Shielding Score and Intrapersonal Level Items

Significant findings were found in all models when multiple regression was performed on items at the intrapersonal level. In each of the 3 models, the belief that shielding can reduce a patient's cancer risk was positively predictive of shielding behavior for radiologic technologists only. As technologist belief that the use of a shield can reduce a patient's cancer risk increased, the behavioral score of using a shield during an examination also increased.

In all 3 models, the belief that the technologist would be more likely to shield a friend or family member over a stranger was negatively predictive of shielding behavior for CT technologists. This suggests that as a technologist's belief that they would shield someone they know over a stranger decreases, their use of shielding decreases. These results can be seen in Table 14.

Table 14.
Multiple Regression Analysis of the Association Between Shielding Behavior Score and Intrapersonal Level Items

B(SE B)						
	Model 1[a]		**Model 2[b]**		**Model 3[c]**	
Intrapersonal Level	Radiologic	CT	Radiologic	CT	Radiologic	CT
Reducing CA Risk	.963(.341)*	1.380(.184)	1.010(-.129)*	1.504(.201)	1.006(.357)*	1.523(.207)
Shld Friend or Family	-.333(-.181)	-1.400(-.259)*	-.277(-.151)	-1.389(-2.57)*	-.276(-.150)	-1.420(-.267)*
More Impt Shld Kid	-.178(-.076)	.812(.117)	-.196(-.084)	.854(.123)	-.194(-.083)	1.047(.153)
Age			.013(.094)	.032(.072)	.012(.017)	.092(.208)
Gender			.163(.041)	-1.181(-.129)	.176(.399)	-1.069(-.118)
Years employed in primary modality					-.052(-.066)	.054(.023)
Years registered in primary modality					.063(.080)	-.478(-.201)

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history
*Significance at p<..01

Shielding Score and Interpersonal Level Items

For the interpersonal level none of the items were found to be significantly associated with the dependent variable of shielding behavior score across any of the 3 models. This was true for both radiologic technology and CT modalities. These findings are reflective of those found in scored interpersonal multivariate analysis. Shield use by other technologists and shield use by friends who are technologists are not predictive of shield use. The results of the multiple linear regression for the interpersonal level can be found in Table 15.

Table 15.
Multiple Regression Analysis of the Association Between Shielding Behavior Score and Interpersonal Level Items

	B(SE B)					
	Model 1[a]		**Model 2[b]**		**Model 3[c]**	
Interpersonal Level	Radiologic	CT	Radiologic	CT	Radiologic	CT
Techs Shld	.019(.011)	.452(.088)	.020(.012)	.740(.145)	.016(.009)	.855(.170)
Friends Shld	-.281(-.160)	.329(.066)	-.243(-.138)	.184(.037)	-.253(-.144)	.061(.012)
Age			.006(.045)	.051(.116)	.002(.016)	.105(.239)
Gender			.480(.121)	-.865(-.094)	.525(.133)	-.705(-.078)
Years employed in primary modality					-.234(-.296)	-.070(-.029)
Years registered in primary modality					.273(.346)	-.269(-.112)

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history

Shielding Score and Organizational Level Items

When multiple regression analyses were performed on items from the organizational level significant findings were found in Model 2[b] for both radiologic and CT technologists and Model 3[c] for only CT technologists. No items were found to be significant in Model 1[a] for either modality. For Model 2[b] having shields available within the examination room and management stressing the importance of shielding were both significant in relation to the dependent variable of shielding behavior score. In Model 3[c] only management stressing the importance of shield use was found to be significant for CT technologists. These findings suggest that as shield importance by management increases, shield use by technologists also increases. Additionally, as shield availability within the examination room increases, shield use behavior by technologists also increases. The results are shown in Table 16.

Table 16.
Multiple Regression Analysis of the Association Between Shielding Behavior Score and Organizational Level Items

	B(SE B)					
	Model 1[a]		Model 2[b]		Model 3[c]	
Organizational Level	Radiologic	CT	Radiologic	CT	Radiologic	CT
Shld Room	.005(.003)	1.258(.203)	-.008(.004)**	1.264(.204)**	-.011(-.006)	1.125(.184)
Shld Portable	.411(.245)	.743(.107)	.420(.250)	.619(.089)	.424(.253)	.378(.055)
Personal Shld	-.040(-.036)	.068(.021)	-.029(-.027)	.076(.024)	-.037(-.034)	.036(.011)
Mngt Shld Imprt	.327(.175)	1.284(.223)	.344(.184)**	1.292(.225)**	.341(.183)	1.409(.250)**
Mngt Incentives	-.194(-.128)	-.928(-.191)	-.181(-.119)	-.851(-.175)	-.198(-.130)	-.750(-.157)
Mngt Reprimands	-.149(-.101)	1.235(.264)	-.098(-.067)	1.391(.297)	-.093(-.063)	1.370(.298)
Reminder Sign	.215(.121)	.244(.505)	.203(.114)	.168(.034)	.220(.124)	.194(.040)
Age			.007(.049)	.055(.046)	-.001(-.005)	.102(.218)
Gender			.418(.107)	-.715(-.075)	.465(.120)	-.504(-.053)
Years employed in primary modality					-.089(-.110)	-.130(-.051)
Years registered in primary modality					.167(.209)	-.076(-.031)

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history
**Significance at p<.05

Shielding Score and Community Level Items

Multiple linear regression analysis for items at the community level revealed that the idea of patients not thinking shielding is important during a medical imaging examination is significant in predicting whether or not a technologist would shield that patient. This was only found to be significant among the radiologic technologist group. These results suggest that as a patient's belief in the importance of shielding during an examination decreased, that technologist shield use also decreases. Results can be viewed in Table 17.

Table 17.
Multiple Regression Analysis of the Association Between Shielding Behavior Score and Community Level Items

	B(SE B)					
	Model 1[a]		Model 2[b]		Model 3[c]	
Community Level	Radiologic	CT	Radiologic	CT	Radiologic	CT
Pt Shld not Impt	-.552(-.253)**	-.171(-.028)	-.582(-.267)*	-.219(-.036)	-.573(-.263)*	-.120(-.020)
Pt Refuse	.348(.183)	-.606(-.100)	.363(.191)	-.555(-.091)	.377(.199)	-.354(-.059)
Pt Preg/Repro Risk	-.276(-.125)	-.019(-.003)	-.324(-.147)	-.054(-.009)	-.343(-.156)	-.057(-.010)
Age			.008(.057)	.037(.084)	.003(.020)	.080(.182)

Gender		.742(.187) -.798(-.087)	.766(.193) -.638(-.071)
Years employed in primary modality			.037(.047) -.036(-.015)
Years registered in primary modality			.011(.014) -.210(-.088)

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history
*Significance at p<.01, **Significance at p<.05

Table 18.
Significant Multivariate Models for Single Social-Ecological Level Items

	B	**SE B**	**CI (95%)**	**p-value**
Model 1[a]				
Radiologic: Reducing CA Risk	.963	.341	.431-1.494	.001
Radiologic: Pt Shld not Impt	-.552	-.253	-.993-(-.112)	.014
CT: Shld Friend or Family	-1.400	-.259	-2.420-(-.381)	.008
CT: Shld Room	1.258	.203	.020-2.496	.046
CT: Mngt Shld Imprt	1.284	.223	.089-2.478	.036
Model 2[b]				
Radiologic: Reducing CA Risk	1.010	.358	.480-1.559	.000
Radiologic: Pt Shld not Impt	-.582	-.267	-1.020-(-.144)	.010
CT: Reducing CA Risk	1.504	.201	.090-2.917	.037
CT: Shld Friend or Family	-1.389	-.257	-2.418-(-.361)	.009
CT: Shld Room	1.264	.204	.022-2.505	.046
CT: Mngt Shld Imprt	1.292	.225	.067-2.517	.039
Model 3[c]				
Radiologic: Reducing CA Risk	1.006	.357	.444-1.569	.001
Radiologic: Pt Shld not Impt	-.573	-.263	-1.018-(-.128)	.012
CT: Reducing CA Risk	1.523	.207	.133-2.912	.032
CT: Shld Friend or Family	-1.420	-.267	-2.432-(-.408)	.006
CT: Mngt Shld Imprt	1.409	.250	.179-2.639	.025

B=Beta coefficient; SE B=Standard error of beta
[a] = unadjusted, [b] = adjusted for technologist characteristics, [c]=adjusted for modality history

Summary of Findings

Significant findings were found with Spearman's correlation for survey items within the intrapersonal, organizational, and community levels. When those items were scored into respective socio-ecological levels, Pearson's correlation analyses only resulted with significant findings for CT technologists on the organizational level.

For multivariate analyses when items were combined into respective Social-Ecological level scores, significant models were found for the organizational level for CT technologists only. None of the models were found to be significant for radiologic technologists when the items were combined into these Social-Ecological level scores. When survey items were examined for each Social-Ecological level but not scored, significant findings were found across all models for both modalities. These findings include intrapersonal and organizational level items for CT technologists and intrapersonal, organizational, and community level items for radiologic technologists.

These analyses suggest that the availability of shields within the medical imaging department and the importance of shielding among the management team are important factors within the organizational level to increase shield use by CT technologists.

CHAPTER 5

DISCUSSION

Introduction

This study offers new insight on how Social-Ecological factors may influence technologist shielding behavior in both radiologic and CT modalities. This is the first study to examine how these factors may contribute to a technologist's use of patient shielding during a medical imaging procedure.

Summary of Findings

Qualitative

The results of the focus groups found that many technologists wanted to provide the best possible care to the patients they were performing examinations on. Technologists felt that although they knew the importance of shield use, other workplace factors were distracting them from applying this knowledge on every examination. Some of the factors mentioned during the focus groups were time constraints from management, patient volume due to increased number of examinations requested by physicians, decreased workforce within their facility, and interdepartmental confusion over when to use shields on certain examinations.

Many also reported patient condition factors that decrease their likelihood to shield a patient for an examination. These included patient isolation status, the criticalness of the patient's situation (ex. trauma), and patient combativeness. Additionally, participants reported that many of their patients do not understand the risk of medical radiation exposure and either think shielding is not important due to this or lack the knowledge to know that they can be shielded for most examinations.

Based off the qualitative findings, technologists believe many of the factors decreasing their shield use are organizationally related. Some of these issues cannot be intervened on due to financial restraints of the organization (hiring employees) or patient condition. However, medical imaging department managers could create a departmental shielding protocol with the assistance of the facilities radiologists to lessen technologist confusion and facilities could educate physicians on examination appropriateness to decrease the medical imaging workload.

Quantitative

Aim 1

Exploratory factor analysis was conducted on the 30 survey items related to behavior and ecological levels. Twenty-one factors met the criteria index of >.50. Due to differences in response choice type, shield availability items were tested separately, which resulted in a total of 5 factors. Shield use is however considered a part of the organizational level. These factors were separated based on the association with 1 of 4 levels of the ecological model: intrapersonal, interpersonal, organizational, and community. Reliability testing was conducted on these combined levels to assess for content validity. Three of the 5 categories had strong reliability of the items to represent their respective level, again shield availability was tested as a separate category.

Aim 2

Technologists tended to be middle aged, female, and Caucasian. Most participants had been registered and working in their primary modality for 15 years or less. A similar percentage of technologists from each modality participated in the survey.

Data analyses revealed that organizational level score was predictive of technologist shield use. This level remained significant even when technologist factors and modality history factors were combined in separate models and analyzed. This suggests that as a technologist's organizational level score increases, their use of shields during examinations also increases. In the CT group, intrapersonal, interpersonal, and community levels were not found to be predictive of shield use behavior. None of the combined Social-Ecological levels were found to be predictive of shield use behavior for radiologic technologists. This remained a constant finding even after adjusting for technologist and modality history factors.

Analysis of single survey items within each of the 4 Social-Ecological levels resulted in significant findings of items in the intrapersonal and organizational levels for both CT and radiologic modalities. The following were predictive of shielding behavior: items related to the belief that shielding can reduce cancer level in a patient, the belief that the technologist was more likely to shield a friend or family member as opposed to a stranger, the availability of shields within the examination room, and the importance management puts on shielding within the facility in which the technologist works. The intrapersonal belief of whether or not the patient thought shielding was important was also predictive of shielding behavior, but only for radiologic technologists.

These findings suggest that the organizational level would be the most effective Social-Ecological model to implement an intervention. Since items related to shield use and management's views of shielding importance, these factors should be included in any future intervention. Radiology managers could easily survey the shields within the CT department to determine if there are an adequate number of shields, if shields are located in the best area within the examination room, and if different types (lead vs. bismuth) and sizes (bariatric and wrap shields) are available to technologists. Since many radiology managers or supervisors also perform medical imaging examinations as part of their daily responsibilities, they should look at their own use of shields during their examinations.

For radiologic technologists these findings suggest that either the Social-Ecological model is not the best theoretical model for explaining shield use among radiologic technologists or that further research is needed to understand the factors that are influencing shield use among this group.

Study Strengths

Methodology Triangulation

This exploratory study employed both qualitative and quantitative data collection guided by a mixed methods research design. This allowed for better understanding of the issues medical imaging technologists face in regards to using shielding on patients during examinations. Quantitative study results complemented some of the qualitative findings from the focus groups, in that organizational management and shield availability are important factors in whether or not shielding is used.

Limitations

Participant Recruitment and Sample Size

This study had several limitations in regards to participant recruitment. Sample size was lower than anticipated when compared with studies addressing similar populations and with the pilot study. After participants were removed due to lack of completed responses, the response rate was 13%. There are a few possible reasons for this low response rate. First, participants' contact information was provided by the ARRT. When agreeing to have information on the ARRT mailing list, individuals provide the email they would like the ARRT to use to contact them. This email address may not be the participant's main email contact and the email may not have been viewed. Second, many of the email addresses listed on the ARRT dataset were associated with the technologist's employer. Some participants may not have had the opportunity to complete the survey at their place of work, may not have felt comfortable taking a survey on shielding behaviors while at their place of work, or may no longer be employed at that facility and therefore no longer have access to that email address. Third, the investigator only requested email addresses through the ARRT database. This database contains mailing addresses and phone numbers for contact also. It is possible that relying on one method of delivery decreased the response rate. Last, some participants may have not responded due to unfamiliarity with the research investigator's contact address and concerns over recent public email hacking and information leaks.

Social Desirability

Shielding patients is a responsibility of medical imaging technologists in order to provide proper care and safety to their patients. Most radiography educational programs stress the importance of shielding to students during their didactic education and clinical experience. This may have led to participants responding differently to shielding questions compared to how they actually perform in the work place. The qualitative portion of the study revealed that technologists were shielding little or never when they could have, however the quantitative study resulted in many responding that they shield often or always. For future studies it may be beneficial to track which examinations they use shielding on during a certain period of time either through participant journal keeping or electronic facility data if available.

Recommendations for Future Research

Future Study 1: Exploring Additional Factors Contributing to Radiologic Technologists' Shield Use

This study did not find any of the 4 Social-Ecological levels analyzed to be statistically significant in relation to shield use among radiologic technologists when combined score was used for analysis, but did find some significant individual items within those Social-Ecological levels. The literature, qualitative findings of this study and the investigator's personal experience in the field show that there is a lack of shield use among radiologic technologists. Additional factors that were not studied in this research may be useful to determining what influences radiologic technologists to use shielding during examinations. Therefore, conducting additional qualitative research, such as focus groups or radiology department observation, with only diagnostic radiology technologists may lead to better insight on the barriers these technologists are facing and how to intervene on those factors.

Additionally, researchers may find past studies on handwashing in the medical community beneficial to understanding shield use among technologists. Just like bacteria on hands, radiation emitted from the x-ray tube is not visual to the human eye. Due to the lack of visibility, individuals may perceive the dangers as less than what they are. Hand washing literature may provide insight on intrapersonal factors that might be affecting their shielding behaviors.

Future Study 2: Improving Response Rate

The low response rate to the national survey indicates that administering the survey through additional contact methods may be beneficial in increasing participation. The email a technologist provides for the ARRT mailing list may not be the best method to contact every participant. By contacting an individual in multiple ways, such as email, phone, and traditional postal mail the investigator may be able to obtain more completed responses. The investigator could send email and traditional postal invitations and then follow up with reminders via phone. These adjusted recruitment strategies should improve the response to the study, allowing for increased statistical power and analyses.

Future Study 3: Exploring CT Technologists Views of Organizational Influence on Shield Use

The study results show the organizational level to be the most significant for increasing shield use among CT technologists. This study tested multiple factors that could contribute to organizational influence on shield use; however, these factors were created from focus groups with technologists locally and may not be nationally representative of the population. The investigator could partner with additional researchers across the country to conduct focus groups targeting CT technologists to gain a better understanding of factors related to organizational influence. This could lead to improved insight on the topic, additional factors that technologists in this region may not experience, and development of a secondary survey instrument in which the results could lay the foundation for an organizational intervention with CT technologists.

Future Study 4: Pilot Intervention with Local CT Technologists on the Organizational Level

Findings from this exploratory research study suggest that an intervention at the organizational level may most efficient in improving shielding rates among CT technologists. Qualitative focus groups were conducted locally in northeast Tennessee that supported the idea that this level was an important factor in shield use. A pilot intervention could be conducted with local healthcare facilities to address the issue of decreased shield use during CT examinations. Through this study and personal experience, the investigator recommends the following components of a local intervention:

1. Observational department analysis to determine the number, types, and location of shields within each CT examination room. Shields should be easily available and within view as a reminder to use shielding. All examination rooms should have at minimum 1 shield available. Additionally, management should be observed to determine their involvement and visual presence within the department.
2. Development of a department shielding protocol that is collaborative between the medical imaging department and the radiologists who will be reading the examinations. The protocol should be written up and posted throughout the department where technologists can easily see it. Technologists need to be made aware of the department shielding protocol.
3. Increase management oversight in departments in which managers and supervisors are not visually present. This will allow managers to gain better understanding of issues occurring in their own department, allowing them to make the changes necessary to increase patient shielding.
4. Technologists within the department need to be held accountable for their shield use. Professional reminders, and in some cases reprimands, should be used when technologists are consistently not applying shields to the patients under their care when it does not interfere with the anatomy of interest.

Contribution to Public Health

With the increasing use of radiography and CT examinations and increasing cumulative doses among members of the public, this study provides insight into the factors that contribute to technologist shield use. While more research is needed, a future intervention to increase the use of shielding among technologists during examinations has the potential to decrease cumulative radiation dose to the radiosensitive organs of the general population. Increased shield use, along with other dose reduction methods mentioned in this study, could eventually reduce patients' lifetime radiation dose and decrease the likelihood of developing radiation-induced cancer due to medical imaging procedures.

Conclusion

This study serves as a starting point for understanding the influence a technologist's environment has on their use of shielding during procedures. Previous literature and personal experience from the investigators work experience in radiology and CT show that technologists are not using shielding as often as should be. Both the qualitative and quantitative results suggest intervention at the organizational level may increase shield use in the CT population, specifically availability of shields and management beliefs. While combined Social-Ecological levels were not found statistically significant in this study for radiologic technologists, some items were. These items relating to intrapersonal beliefs, organization, and community may be useful in further research to discover the best intervention level for radiologic technologists. Additionally, future studies and possible interventions need to consider the structure of the department in which they are studying, whether those departments have separate radiography and CT departments or if they are combined and technologists are performing both modality examinations, and tailor interventions to department configuration.

REFERENCES

American Cancer Society. (2016). *Cancer Facts and Figures 2016.* [PDF document]. Retrieved August, 2015 from https://www.cancer.org/content/dam/cancer-org/research/cancer-facts-and-statistics/annual-cancer-facts-and-figures/2016/cancer-facts-and-figures-2016.pdf

American College of Radiology. (2017). *ACR Appropriateness Criteria.* [PDF document]. Retrieved September, 2017 from https://www.acr.org/Quality-Safety/Appropriateness-Criteria

American Registry of Radiologic Technologists. (2015). *ARRT Standard of Ethics.* [PDF document]. Retrieved September, 2015from https://www.arrt.org/pdfs/Governing-Documents/Standards-of-Ethics.pdf

American Registry of Radiologic Technologists. (2017). *Radiography Examination Content Specifications.* [PDF document]. Retrieved September, 2017 from https://www.arrt.org/docs/default-source/discipline-documents/radiography/rad-content-specifications.pdf

Bartlett, J., Kotrlik, J., & Higgins, C. (2001). Organizational research: Determining appropriate sample size in survey research. *Information Technology, Learning, and Performance Journal, 19*(1), 43-50.

Beaconsfield, T., Nicholson, R., Thornton, A., & Al-Kutoubi, A. (1998). Would thyroid and breast shielding be beneficial in CT of the head? *European Radiology, 8*, 664-667.

Berrington de Gonzalez, A., Mahesh, M., Kim, K., Bhargavan, M., Lewis, R., Mettler, F., & Land, C. (2009). Projected cancer risks from computed tomographic scans performed in the United States in 2007. *Archives of Internal Medicine, 169*(22), 2071-2077.

Birks, M., & Mills, J. (2015). *Grounded theory: A practical guide* (2nd ed.). London: SAGE Publications Ltd.

Bontrager, K. (2002). *Pocket atlas: Handbook of radiographic positioning and techniques* (4th ed.). Gilbert, AZ: Bontrager Publishing Inc.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design.* Cambridge, MA: Harvard University Press.

Brown, V. (2015). Using the social ecological model to inform community needs assessments. *Journal of Family and Consumer Sciences, 107*(1), 45-51.

Bushong, S. (2017). *Radiologic science for technologists: Physics, biology, and protection* (11th ed.). St. Louis, MO: Elsevier.

Cardis, E., Vrijheid, M., Blettner, M., Gilbert, E., Hakama, M., Hill, C., … Veress, K. (2005). Risk of cancer after low doses of ionizing radiation: retrospective cohort study in 15 countries. *British Journal of Medicine, 331*(7508), 77.

Care Quality Commission. (2014). *IR(ME)R Annual Report 2013*. [PDF document]. Retrieved September, 2015from http://www.cqc.org.uk/sites/default/files/20140721_irmer_annual_report_final.PDF

Cheung, K. (2013). *Establishing a radiation safety culture in health care. 2nd WHO Global Forum on Medical Devices Geneva.* [PDF document]. Retrieved September, 2015 from http://www.who.int/medical_devices/global_forum/Workshop_22_Medical_physics_3.pdf

Clark, R., & Valentin, J. (2009) The history of ICRP and the evolution of its policies. *Annals of the ICRP*, *39*(1), 75-110. https://doi.org/10.1016/j.icrp.2009.07.009

Cooper, M., Cohen, M., Piersall, K., & Apgar, B. (2009). *Study of Neonates Exposure Index*. [PDF document]. Retrieved September, 2015 from http://www.agfahealthcare.com/he/usa/en/binaries/Study_Neonates_Exposure%20Index%201,%20Indiana%20University_tcm561-104773.pdf

Dunn, R., Kalich, K., Henning, M., & Fedrizzi, R. (2015). Engaging field-based professionals in a qualitative assessment of barriers and positive contributors to breastfeeding using the social ecological model. *Maternal and Child Health Journal, 19*(1), 6-16

Einstein. (2012). Effects of radiation exposure from cardiac imaging: How good are the data? *Journal of the American College of Cardiology, 59*(6), 553-565.

Evans, K., Bodmer, J., Edwards, B., Levins, J., O'Meara, A., Ruhotina, M., … Carney, J. (2015). An exploratory analysis of public awareness and perception of ionizing radiation and guide to public health practice in Vermont. *Journal of Environmental and Public Health*, http://dx.doi.org/10.1155/2015/476495

Fazel, R., Krumholz, H., Wang, Y., Ross, J., Chen, J., Ting, H., … Nallamothu, B. (2009). Exposure to low-dose ionizing radiation from medical imaging procedures. *New England Journal of Medicine, 361*, 849-857.

Ferrer, H., Trotter, C., Hickman, M., & Audrey, S. (2014). Barriers and facilitators to HPV vaccination of young women in high-income countries: a qualitative systematic review and evidence synthesis. *BioMed Central Public Health*, *14*, 700.

Food and Drug Administration. (2017). *Radiation-emitting products: appropriate use.* Retrieved September, 2017 from https://www.fda.gov/Radiation-EmittingProducts/RadiationSafety/RadiationDoseReduction/ucm299354.htm

Food and Drug Administration. (2017). *What are the radiation risks from CT?* Retrieved September, 2017 from https://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/MedicalImaging/MedicalX-Rays/ucm115329.htm

Gibson, D., & Davidson, R. (2012). Exposure creep in computed tomography. *Academic Radiography*, *19*(4), 458-462.

Health Physics Society. (2012). *Radiation safety culture. Position statement of the Health Physics Society.* [PDF document]. Retrieved August, 2015 from

http://hps.org/documents/radiationsafetyculture_ps026-0.pdf

Health Physics Society. (2015). *FAQ lead garments.* Retrieved September, 2015from: https://hps.org/publicinformation/ate/faqs/leadgarmentsfaq.html

Hendee, W., & O'Connor, M. (2012). Radiation risks of medical imaging: separating fact from fantasy. *Radiology, 264(2),* 312-321.

Herrmann, R., Fauber, T., Gill, J., Hoffman, C., Orth, D., Peterson, P., … Odel, T. (2012). *Best practices in digital radiography* [White paper]. Retrieved September, 2015 from ASRT website: https://www.asrt.org/docs/default-source/whitepapers/asrt12_bstpracdigradwhp_final.pdf

Holden, D., Strazza-Moore, K., & Holliday, J. (1998). Health education for a breast and cervical cancer screening program: using the ecological model to assess local initiatives. *Health Education Research, 13*(2), 293-299.

Hricak, H., Brenner, D., Adelstein, S., Frush, D., Hall, E., Howell, R., … Wagner, L. (2011). Managing radiation use in medical imaging: a multifaceted challenge. *Radiology, 258*(3), 889-905.

Gori, T., & Münzel, T. (2012). Biological Effects of Low-Dose Radiation: of Harm and Hormesis. European Heart Journal, 33, 292-295

International Atomic Energy Agency. *Module IX: Dose-effect curves: Deterministic and stochastic effects of radiation* [PowerPoint slides]. Retrieved September, 2015 from www-pub.iaea.org\\MTCD\\publications\\PDF\\eprmedt\\Day_2\\Day_2-7.pps

International Atomic Energy Agency and World Health Organization. (2013). *Bonn call for action: 10 actions to improve radiation protection in medicine in the next decade.* [PDF document]. Retrieved August, 2015 from https://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/MedicalImaging/MedicalX-Rays/ucm115329.htm

International Commission on Radiological Protection. (2007). The 2007 recommendations of the International Commission on Radiological Protection. *Annals of the IRCP, 37*(2-4), 1-332. https://doi.org/10.1016/j.icrp.2007.10.003

International Commission on Radiological Protection. (2009). *The International Framework for Radiation Safety* [PowerPoint slides]. Retrieved August, 2015 from https://www.epa.ie/pubs/reports/radiation/RPII_ICRP_Int_Frame_Rad_09.pdf

Johnston, J., Killion, J., Vealé, B., & Comello, R. (2011). U.S. technologists' radiation exposure perceptions and practices. *Radiologic Technology, 82*(4), 311-320.

Köteles, G.J. (1998). The low dose dilemma. *Central European Journal of Occupational and Environmental Medicine, 4*(2), 103-113.

Krille, L., Hammer, G., Merzenich, H., & Zeeb, H. (2010). Systematic review on physician's knowledge about radiation doses and radiation risks of computed tomography. *European Journal of Radiology, 76*, 36-41.

Kumar, S., Quinn, S., Kim, K., Musa, D., Hilyard, K., & Freimuth, V. (2012). The social ecological model as a framework to determinants of 2009 H1N1 influenza vaccine uptake in the United States. *Health Education and Behavior, 39*(2), 229-243.

Lee, C., Haims, A., Monico, E., Brink, J., & Forman, H. (2004). Diagnostic CT scans: assessment of patient, physician, and radiologist awareness of radiation dose and possible risks. *Radiology, 231*, 393-398.

MacKay, M., Hancy, C., Crowe, A., D'Rozario, R., & Ng, C. (2012). Attitudes of medical imaging technologists on use of gonad shielding in general radiography. *The Radiographer, 59*(2), 35-39.

Mettler, F., Bhargavan, M., Faulkner, K., Gilley, J., Ibbott, G., Lipoti, J., … Yoshizumi, T. (2009). Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other sources – 1950-2007. *Radiology, 253*(2), 520-531.

Mohan, A., Hauptmann, M., Freedman, M., Ron, E., Matanoski, G., Lubin, J., … Linet, M. (2002). Cancer and other causes of mortality among radiologic technologists in the United States. *International Journal of Cancer*, *103*, 259-267.

Morford, K., & Watts, L. (2012). Bismuth shielding during CT exams: a literature review. *Radiology Management*, *34*(3), 45-47.

Naar-King, S., Montepiedra, G., Garvie, P., Kammerer, B., Malee, K., Sirois, P., Aaron, L., & Nichols, S. (2013). Social ecological predictors of longitudinal HIV treatment adherence in youth with perinatally acquired HIV. *Journal of Pediatric Psychology, 38*(6), 664-674.

National Council on Radiation Protection and Measurements (NCRP). (2009). *Scientific committee 6-2 on radiation exposure of the U.S. population, ionizing radiation exposure of the population of the United States: recommendations of the National Council on Radiation Protection and Measurements.* Bethesda, MD.

National Radiation Laboratory. (ND). *Ionizing radiation incidents in diagnostic imaging.* [PDF document]. Retrieved September, 2015 from https://www.health.govt.nz/system/files/documents/pages/incidents-diagnosticimaging.pdf

Nuclear Radiation Agency. (1996). *Chernobyl: ten years on – radiological and health impact.* [PDF document]. Retrieved September, 2015 from https://www.oecd-nea.org/rp/chernobyl/chernobyl-1995.pdf

Onwuegbuzie, A., Dickinson, W., Leech, N., & Zoran, A. (2009). A qualitative framework for collecting and analyzing data in focus group research. *International Journal of Qualitative Methods, 8*(3).

Preston, D., Ron, E., Tokuoka, S., Funamoto, S., Nishi, N., Soda, M., Mabuchi, K., & Kodama, K.. (2007). Solid cancer incidence in atomic bomb survivors: 1958-1998. *Radiation Research, 168*(1), 1-64.

Reagan, J., & Slechta, A. (2010). Factors related to radiation safety practices in California. *Radiologic Technology, 81*(6), 538-547.

Salazar, M., & Beaton, R. (2000). Ecological model of occupational stress: application to urban firefighters. *American Association of Occupational Health Nurses, 48*(10), 470-479.

Siemens Healthcare. (ND). Biological effects of radiation. Retrieved August, 2015 from https://www.healthcare.siemens.pl/diagnostyka-obrazowa/wlasciwa-dawka/find-out-about-the-basics-of-radiation/facts-about-radiation

Slechta, A., & Reagan, J. (2008). An examination of factors related to radiation protection practices. *Radiologic Technology, 79*(4), 297-305.

Sodickson, A., Baeyens, P., Andriole, K., Prevedello, L., Nawfel, M., Hanson, R., & Khorasani, R. (2009). Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. *Radiology, 251*(1), 175-184.

Sorra, J., Famolaro, T., Dyer, N., Nelson, D., & Khanna, K. (2008). *Hospital survey on patient safety culture 2008 comparative database report (*AHRQ Publication No. 08-0039). Rockville, MD; Agency for Healthcare Research and Quality.

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). (2010). UNSCEAR 2008 Report to the general assembly: Volume 1 with scientific annexes [PDF document]. Retrieved September, 2015 from http://www.unscear.org/docs/publications/2008/UNSCEAR_2008_Report_Vol.I.pdf

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). (2008). Effects of ionizing radiation. UNSCEAR 2006 Report. Volume 1. Scientific Annex A: Epidemiological Studies of Radiation and Cancer (New York: United Nations).

Wiest, P., Locken, J., Heintz, P., & Mettler, F. (2002). CT scanning: a major source of radiation exposure. *Seminars in Ultrasound, CT, and MR, 23*(5), 402-410.

World Health Organization. (2008). *Global initiative on radiation safety in healthcare settings. Technical Meeting Report.* [PDF document]. Retrieved September, 2015from http://www.who.int/ionizing_radiation/about/GI_TM_Report_2008_Dec.pdf

APPENDICES

APPENDIX A

Focus Group Moderator Guide

Focus Group Moderator Guide

Questions:

Education (Intrapersonal)

1. Think back to your radiologic education. What type of training did you receive on shields?
2. Do you feel that the education on shielding was enough to prepare you for your career?
    a. If no, can you explain how it was lacking?
3. What differences do you see between shielding taught in school vs. what you see every day at work?
4. Are there any procedures that you do not feel confined in using a shield?
5. For those of you who do CT, what type of training or education were you provided for shielding during CT exams?
6. What type of CT exams do you use shielding for? Where do you position the shield during those exams?

Behaviors (Intrapersonal)

1. How often do you shield your patients during examinations?
2. What situations do you often find yourself shielding the patient?
3. Are there any groups of individuals that you shield most often?
    a. If so, which groups of people? Why?
4. Are there any differences in how you shield a middle aged individual compared to a child?
    a. If so, what are those differences?
5. What are some of the reasons/situations you would not use shielding?
6. In a situation in which shielding is not conveniently available what do you do?
7. Does how you shield a patient when you are alone differ from how you would if a supervisor or peer were nearby?
    a. If yes, what are the differences?

Beliefs (Intrapersonal)

1. Which groups do you feel are most sensitive to radiation? (ages, genders, reproductive status)
2. What do you believe are the possible benefits to the patient if you use shielding?
3. What do you believe are the possible harms to the patient if you do not shield them?
4. How long after radiation exposure will someone have health effects from radiation exposure?
5. What examinations do you believe shielding cannot be used on?

Interpersonal

1. What does ALARA (as low as reasonably achievable) mean to you?
2. During which procedures do you feel shielding is unnecessary?
3. Would you be more likely to shield friends and/or family members than you would a complete stranger?

4. Thinking of technologists that you are friends with, how does their shielding behaviors influence your behavior to shield?
1. Has another technologist ever had to remind you to shield or have you had to remind someone? If so, how did you or the other technologist take the reminder? What was said?
2. If you noticed a fellow tech shielding nearly all of their patients, would this affect your shielding use? If yes, how so?
3. When performing an exam do you ever find yourself rushing through it to go back to whatever you were doing beforehand?
    a. If yes, what are those activities you rush back to?

Workplace (Organizational)

1. Does the facility in which you work have written protocols in relation to shielding?
    a. If yes, what are those protocols?
2. Thinking of the facility in which you work, what factors make shielding difficult?
3. What types of shields do you have available at the facility in which you work?
4. Are there any types of shield that you do not have access to which you feel are needed during your job?
    a. If yes, which kind?
5. Have you ever run into a situation in which you were unable to use the shields available to you due to body habitus? Did you try any other methods to shield? If so, what did you try?
6. Does the facility in which you work provide continuing education on shielding?
7. Can you recall any situation in which yourself or another employee was reprimanded for not shielding a patient?
    a. If yes, what consequence occurred?
8. What type of incentives could be provided by your employer that would make you most likely to increase your use of shielding?
9. What types of repercussions at work would make you shield more often?
10. Who would you rather have remind you to shield (supervisor, friend, other tech that is not a friend, student) and why?
11. What barriers at work make it difficult to shield your patients?
12. What factors at work make shielding easier?
13. What role do you think technology (i.e. computers and smart phones) access while at work plays in shielding?
14. How do the radiologists at your facility work with technologists to reduce patient dose? Does it include shielding recommendations?

Community

1. Do you feel that the public has enough knowledge about radiation risks?
2. How often are patients concerned about radiation during an exam?
3. How often do patients ask you to shield them?

4. If a patient refuses to be shielded, how do you handle that situation?

Public Policy

1. If you had questions on shielding or radiation dose where would you go to find an answer?
2. If registering bodies (ARRT) started reprimanding technologists who repeatedly were found to not shield their patients how would it affect your behaviors?
3. What type of information do you think needs to be released by organizations (ARRT, ASRT, CDC, NCRP, etc) to technologists to increase shielding?
4. Do you think the information that technologists receive should differ from the type that the general population receives on radiation?
    a. If yes, how so?

APPENDIX B

Focus Group Flyer

Participate in a Focus Group

Are you interested in participating in a focus group to discuss your thoughts on patient shielding during X-ray and CT examinations?

East Tennessee State University College of Public Health Doctoral Student is looking for participants:

- Men and women aged 18 or older
- Currently registered by the ARRT in radiography (R) or computed tomography (CT)
- Compensation will be provided for a 90 minute focus group

Shielding in Medical Imaging Focus Group
Contact: Megan Housenick-Lee RT(R)(CT)(MR)
housenicksla@etsu.edu or 423-946-5088

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Shielding in Medical Imaging Focus Group
Contact: Megan Housenick-Lee RT(R)(CT)(MR)
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APPENDIX C

Online Survey Instrument

Dear Participant:

My name is Megan Housenick-Lee, and I am a doctoral student at East Tennessee State University. I am working on a DrPH in Community and Behavioral Health. In order to finish my studies, I need to complete a research project. The name of my research study is Barriers to Shielding in Medical Imaging.

The purpose of this study is to determine barriers that technologists face in regards to shielding patients during examinations. I would like to give a brief online survey to registered radiologic and computed tomography (CT) technologists using SurveyMonkey. It should take about 20 minutes to complete. You will be asked questions about your beliefs, attitudes, behaviors, and knowledge on shielding patients during examinations. Since this project deals with personal opinions and behaviors, it is not expected to cause you stress or discomfort. You may feel better after you have had the opportunity to express yourself and contribute to the profession by revealing barriers you face daily in your work environment. There are no direct benefits to participating in this study. At the end of the study you will have the opportunity to provide contact information in order to be entered into a random drawing for an iPad. This contact page will be separate from your survey answers and cannot be linked back to the survey you complete. Per East Tennessee State University protocol, if you are selected to receive the iPad, you will need to provide your full name, full mailing address, and social security number.

Your confidentiality will be maintained to the degree permitted by the technology used. Specifically, no guarantees can be made regarding the interception of data sent via the Internet by any third parties, as is the case with emails. In other words, we will make every effort to ensure that your name is not connected with your responses. Specifically, SurveyMonkey has security features that will be enabled: IP address will not be collected and each participant is assigned a unique identifier. Although your rights and privacy will be maintained, the ETSU IRB (for non-medical research), study sponsor the American Society of Radiologic Technologists (ASRT), and personnel particular to this research have access to the study records.

If you do not want to fill out the survey, it will not affect you in any way. You may skip any questions you do not wish to answer or simply exit the online survey form if you wish to remove yourself entirely.

Participation in this study is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected.

If you have any research-related questions or problems, you may contact me, Megan Housenick-Lee at 423-946-5088. We are working on this project together under the supervision of Dr. Katie Baker. You may reach her at 423-439-4332. Also, the chairperson of the Institutional Review Board at East Tennessee State University is available at 423-439-6054 if you have questions about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or your can't reach the study staff, you may call an IRB Coordinator at 423-439-6002.

Sincerely,
Megan

* 1. Would you like to continue to the survey?

○ Yes

○ No

* 2. Are you currently registered with the American Registry of Radiologic Technologists (ARRT)?

- ◯ Yes
- ◯ No

3. Please provide your current age:

4. Please select your gender:

- Male
- Female

5. Which of the following racial groups best describes you?

- American Indian/Alaska Native
- Asian
- Black/African American
- Native Hawaiian/other Pacific Islander
- White/Caucasian

6. Do you consider yourself hispanic or latino?

- Yes
- No

7. How many years have you been employed in your primary modality?

- 0-5 years
- 6-10
- 11-15
- 16-20
- 21-25
- 26-30
- 31-35
- 36 years or more

8. How many years have you been registered by the ARRT in your primary modality?

- 0-5 years
- 6-10
- 11-15
- 16-20
- 21-25
- 26-30
- 31-35
- 36 years or more

9. Please select how often you perform the following:

	Never	Rarely	Sometimes	Often	Always
Shield patients when the shield does not interfere with the anatomy of interest.	◯	◯	◯	◯	◯
Shield children 12 years old or younger.	◯	◯	◯	◯	◯
Shield children between the ages of 13 and 18 years old.	◯	◯	◯	◯	◯
Shield individuals that are of reproductive age (19-55 years old).	◯	◯	◯	◯	◯
Shield individuals who are over 56 years old.	◯	◯	◯	◯	◯
Ask patients of child-bearing age if they could be pregnant.	◯	◯	◯	◯	◯
Shield pregnant women.	◯	◯	◯	◯	◯

10. Please select how strongly you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I believe I received adequate training on shield use while enrolled in my radiography program.	○	○	○	○	○
The use of shielding can reduce the patient's direct radiation exposure to radiosensitive organs.	○	○	○	○	○
It is more important to shield a child than an elderly patient.	○	○	○	○	○
I am more likely to shield a family member or friend as opposed to a stranger.	○	○	○	○	○
Shielding is an important factor in reducing cancer risk in patients.	○	○	○	○	○
I want to provide the best care to my patients.	○	○	○	○	○
Shielding patients is a waste of my time.	○	○	○	○	○
I believe it is important to shield patients in contact isolation.	○	○	○	○	○

11. Please select how often you experience the following situations at the facility in which you currently work:

	Never	Rarely	Sometimes	Often	Always
Shields are easily within reach in the radiographic exam room.	○	○	○	○	○
There are shields on the portable machines at my facility.	○	○	○	○	○
Use my personal lead apron to shield a patient.	○	○	○	○	○

12. Please answer how <u>strongly you agree or disagree</u> with the following statements about the <u>facility in which you currently work</u>:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
My co-workers shield all patients as long as it does not interfere with the examination.	○	○	○	○	○
Shielding is very important within the facility in which I work.	○	○	○	○	○
Management stresses the importance of shield use to employees often.	○	○	○	○	○
I would be more likely to use shielding if I were to see more technologists at my facility using shielding.	○	○	○	○	○
I would be more likely to shield if I saw technologists who I am friends with use shielding.	○	○	○	○	○
I would be more likely to shield if management offered incentives for shielding.	○	○	○	○	○
I would be more likely to shield if management reprimanded employees who were caught not shielding when they should.	○	○	○	○	○
I believe a sign reminding me to shield would increase my use of shielding.	○	○	○	○	○
My facility has a protocol in place about when to use shielding on patients.	○	○	○	○	○

13. Please answer how strongly you agree or disagree with the following statements about the community in which you reside:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly agree
Patients do not think shielding is important.	◯	◯	◯	◯	◯
I often have patients who refuse to be shielded.	◯	◯	◯	◯	◯
Most patients are only aware of the medical radiation health risks in relation to pregnancy and/or reproduction.	◯	◯	◯	◯	◯

* 14. Is your current primary modality in computed tomography (CT)?

- ◯ Yes
- ◯ No

15. Please answer with how strongly you agree or disagree with the following statements in regard to CT ONLY:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I have the shielding I need to protect my patients from radiation during their CT exam.	○	○	○	○	○
I have multiple kinds of shields available.	○	○	○	○	○
Sometimes I use multiple shields at once because the ones I have access to are not large enough to cover the patient.	○	○	○	○	○
I have access to a breast shield.	○	○	○	○	○
I have access to an eye shield.	○	○	○	○	○
I have access to a thyroid shield.	○	○	○	○	○
I have access to bismuth shields.	○	○	○	○	○
I try to shield all patients during CT as long as it does not interfere with the anatomy of interest.	○	○	○	○	○
When shielding the reproductive organs, I wrap the shield entirely around my patient.	○	○	○	○	○

* 16. Would you like to be entered in the drawing for 1 of 2 iPads?

- ◯ Yes
- ◯ No

17. Please enter your contact information so that we may contact you if you are randomly selected for an iPad.

Name	
Email Address	
Phone Number	

Thank you for taking the time to participate in this survey.
Your input is greatly appreciated.

VITA

MEGAN ELIZABETH HOUSENICK-LEE

Education:	A.S. Radiography, South College, Knoxville, Tennessee 2007
	B.S. Allied Health, South College, Knoxville, Tennessee 2007
	M.P.H. Community and Behavioral Health, East Tennessee State University, Johnson City, Tennessee 2012
Professional Experience:	MRI Technologist 2012-Present
	CT Technologist 2008-2012
	Diagnostic Radiology Technologist 2007-2008
	Research Assistant, East Tennessee State University, College of Public Health, 2010-2013
Professional Certifications:	Registered MRI Technologist, 2015
	Registered CT Technologist, 2009
	Registered Radiologic Technologist, 2007
	Certified Health Education Specialist, 2012